Chapter 3

Semi-quantitative risk assessments – The Relative Risk Model

Renée Bartolo, Rick van Dam & Peter Bayliss

Contents

Executive summary **164**

3.1 Introduction **166**

3.2 Relative Risk Model methodology **168**

3.2.1 Definitions 168

3.2.2 Problem Formulation 170

3.2.3 Conceptual models 188

3.2.4 Risk Analysis 196

3.2.5 Risk Characterisation 201

3.3. Risk Characterisation for the Northern Tropical Rivers study area **202**

3.3.1 Habitats 202

3.3.2 Pressures/Threats 203

3.3.3 Total Relative Risk 206

3.3.4 Total sum of threats 210

3.3.5 Ecological Assessment Endpoints 211

3.4. Risk characterisation for the Daly River catchment **216**

3.4.1 Habitats 216

3.4.2 Pressures/Threats 217

3.4.3 Total Relative Risk 221

3.4.4 Total sum of threats 222

3.4.5 Ecological Assessment Endpoints 223

3.5 Sensitivity Analysis **226**

3.5.1 Combining ecological assessment endpoints 226

3.5.2 Use of hectares compared with percentage of area cover 228

3.5.3 Stakeholder ranking analysis 229

3.5.4 Use of particular spatial data 229

3.6 Discussion **232**

3.6.1 Issues in defining ecological assessment endpoints 232

3.6.2 Uncertainty 233

3.6.3 Use of spatial data 234

3.6.4 Utility of the RRM: Advantages and limitations in the application to tropical rivers ecological risk assessment 235

3.7 Summary and conclusions **239**

3.8 References **240**

Appendices **245**

Appendix 1: Land Use Definitions and ALUM Classification (Version 5) 246

Appendix 2: ‘Environ’ categories selected from Queensland NVIS data to create riparian coverage’s 256

Appendix 3: Summary of sources of uncertainty for selected pressures/threats and habitats and qualitative ranking of uncertainty level at the Northern Tropical Rivers scale 270

Executive summary

This chapter focuses on the application of the Relative Risk Model (RRM) as a regional risk assessment tool at two scales: the Northern Tropical Rivers; and the Daly River catchment. The RRM has not previously been applied to a large region such as at the Northern Tropical Rivers scale, and results suggest that it is the most appropriate tool to conduct a semi-quantitative ecological risk assessment at pancontinental scales. It is important to note, however, that the application of the RRM at the two scales represents two models whereby the results from one model can not be compared to the other model due to the relative nature of the RRM. The information collated under Chapter 2 has been used as a basis for informing the development of the RRM in this study.

In the problem formulation phase of the risk assessment, information from stakeholders (workshops conducted for this study and existing reports utilised in Chapter 2) was a key guiding input in the development of ecological assessment endpoints and conceptual models. The development of the Daly River catchment conceptual model was an iterative process involving the input of expert stakeholders from government, NGOs and research institutions.

Spatial data were the primary data source for the risk analysis phase and have been documented in detail in terms of limitations as part of the uncertainty component of the risk assessment. For the Northern Tropical Rivers, 51 risk regions were created based on river basins (catchments) and 18 risk regions were created for the Daly River catchment based primarily on sub-catchments. As part of the RRM calculations, pressures/threats and habitats were ranked based on percentage of areal cover within each risk region.

Results of the risk characterisation phase for the Northern Tropical Rivers are summarised as follows:

- Based on total relative risk calculated from the RRM, the risk regions at high risk from the multiple pressures/threats specified in the model are (from highest risk): Adelaide River (NT); Finniss River (NT); Mitchell River (Qld); Leichhardt River (Qld); Flinders River (Qld); Gilbert River (Qld); Daly River (NT); and Mary River (NT). Conversely, the risk regions with the lowest total relative risk scores are (from lowest risk); Blyth River (NT); Goomadeer River (NT); and Walker River (NT).
- The total sum of threats analysis shows that grazing natural vegetation has the highest relative score followed by the presence of feral pigs and altered fire regime. Grazing natural vegetation land use has the highest percentage of land cover across the risk regions. The risk regions with the highest percentage of grazing natural vegetation are the Flinders Rivers, followed by the Norman and Leichhardt Rivers (all located in Queensland).
- The relative risk scores for the chosen ecological assessment endpoints indicate that the highest total risk is to maintenance of biodiversity. Conversely, the ecological assessment endpoint with the lowest total risk is maintenance of flow regime.

Results of the risk characterisation phase for the Daly River catchment are summarised as follows:

- Based on total relative risk calculated from the RRM, the risk regions at high risk from the multiple pressures/threats specified in the model are (from highest risk): Daly River; Douglas and Katherine Rivers; Green Ant Creek; King and Dry Rivers; Limestone Creek; and Daly River Estuary. Conversely, the risk regions with the lowest total relative risk

scores are (from lowest risk); Upper Katherine River; Seventeen Mile Creek; and Hayward Creek.

- The total sum of threats analysis shows that grazing natural vegetation has the highest relative score followed by transport and communications and land clearing. As with the application of the RRM for the Northern Tropical Rivers, grazing natural vegetation land use has the highest percentage of land cover across the risk regions. The risk regions with the highest percentage of grazing natural vegetation are Limestone Creek and Green Ant and Hayward Creeks.
- The relative risk scores for the ecological assessment endpoints indicate that the highest total risk is to maintenance of biodiversity. Conversely, the ecological assessment endpoint with the lowest total risk is maintenance of perennial flow.

Sensitivity analysis was an important component in documenting uncertainty as part of the risk characteristaion phase. A number of sensitivity analyses were implemented indicating the following:

- The combining of maintenance of aquatic threatened species and water quality endpoints in an earlier iteration of the Daly River catchment RRM had no significant effect on the total relative risk ranks.
- The use of percentage areal cover compared with number of hectares within a risk region for ranking of habitats and pressures and threats affects the risk ranks that comprise inputs to the total relative risk calculation.
- Stakeholder interval analysis for a subset of five of the Daly River catchment risk regions resulted in no change to the risk ranks, indicating the RRM is representative of stakeholder perceptions of the interaction between pressures/threats and habitats.
- Choice of spatial data used as inputs can affect risk ranks as shown by the example of two ‘riparian’ datasets tested for the Daly River catchment.

Other issues of uncertainty have been qualitatively documented including the defining of ecological assessment endpoints, development of conceptual models, the use of spatial data and identification of information gaps. Further work is required to quantify uncertainty in this study.

The advantages and limitations of the RRM approach are summarised at the end of this chapter based on our application. We have found the RRM to be a robust method for assessing the impact of multiple pressures/threats on multiple ecological assessment endpoints. Perhaps one of the major benefits is the ability to use the results as a high level screening tool for decision makers in prioritising further research or management programs. Finally, the ability to produce maps as an output facilitates communication with stakeholders.

3.1 Introduction

A semi-quantitative approach to determining an overall hazard/risk ranking for each of the Northern Tropical Rivers catchments was developed that relies on some key spatial data collected through the inventory sub-project of the TRIAP (Lukacs & Finlayson 2008) and other available information on the severity and extent of the pressures and threats. A spatially explicit methodology, using a Geographic Information System (GIS), is a practical means by which to characterise ecological risk. A spatially-explicit ERA can be defined as estimating the differences in risk for different locations (Woodbury 2003). In a spatial context, and of relevance to this particular project, is the fact that water catchments are increasingly being used as the unit for integrated landscape assessment and management (Aspinall and Pearson 2000; Serveiss 2001).

The use of GIS facilitates the incorporation of multiple anthropogenic and natural threats at the regional level. Within this context, GIS and spatial analysis have been used in numerous ERA applications (Hession et al 1996; Kienast et al 1996; Hogsett et al 1997; Aspinall and Pearson 2000; Gordon and Majumder, 2000; Diamond and Serveiss 2001; Ferdinands et al 2001; Gustafson et al 2001; McDonald and McDonald 2002; Preston and Shackelford 2002; Rouget et al 2002; Xu et al 2004; Billington 2005). Also see Bayliss et al (2006) for an ecological risk assessment of Magela floodplain from landscape-wide risks such as invasive species (wetland weeds & pig rooting damage) and uncontrolled fire. The landscape risk assessments were conducted spatially and combined with point-source risks to downstream surface water quality from three major pollutants released from Ranger uranium mine.

In this project, we have adopted the Relative Risk Model (RRM) (Landis and Wiegers 1997) to assess, semi-quantitatively, ecological risks at the regional scale. The RRM is a robust methodology that incorporates spatial variability at a large scale to examine the interaction of multiple threats to habitats, and their effects (impacts) on assessment endpoints. The method has been shown to direct the focus of investigative studies, data collection and the decision making process (Landis and Wiegers 1997). Figure 3.1 illustrates the difference between a risk assessment in the 'traditional' sense of local site application and at a diffuse regional level. Landis and Wiegers (1997) define the following terms used in the RRM as follows:

- Sources – group of stressors (threats); and
- Habitats – group of receptors; where the receptors reside.

The RRM has been applied successfully in numerous studies and environments including: the marine environment of a fjord in Alaska (Wiegers et al 1998); Mountain River catchment in Tasmania, Australia (Walker et al 2001); an Atlantic Rain Forest reserve in Brazil (Moraes et al 2002); the Codorus Creek Watershed, Pennsylvania (Obery and Landis 2002); a near shore marine environment, Cherry Point, USA (Hayes and Landis 2004); and threats to sensitive species from military land uses in New Mexico and Texas (Andersen et al 2004).

Relative risk estimates are determined by combining source and habitat ranks for the specific regional catchments under assessment. These risks are relative and cannot be used to compare against other risk regions outside the application of the model. In the process, risk characterisation results in a comparison of risk estimates among sub-regions, sources, habitats and endpoints to identify: the sub-regions where most risk occurs; the sources contributing the most risk; the habitats where most risk occurs; and the ecological assets most at risk in the study area (Hayes and Landis 2004).

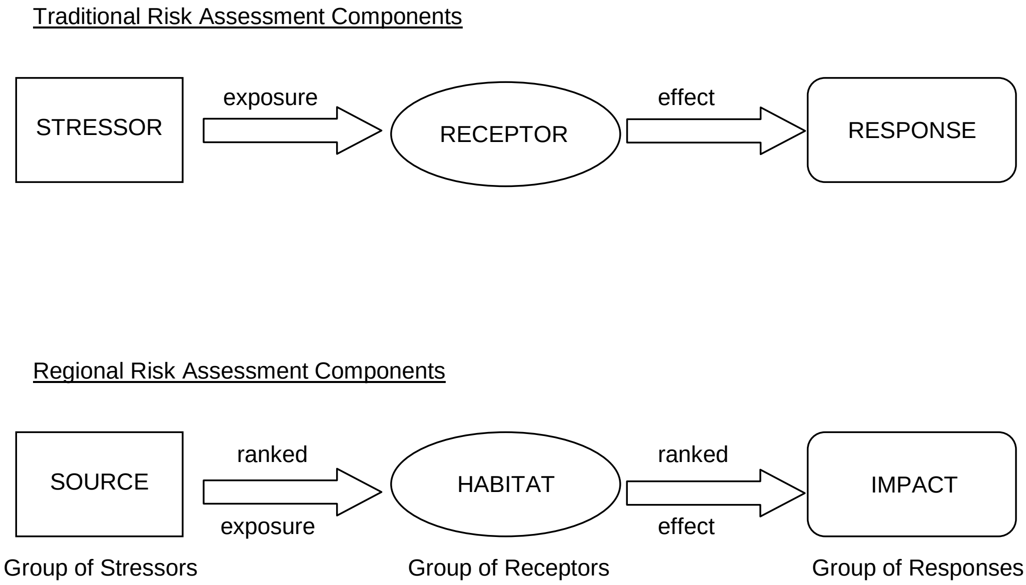


Figure 3.1 Comparison of risk components applied at the traditional and the regional levels (Landis and Wiegers 1997). *Source* in the context of this project equates to a *group of threats* and *habitat* can be related to a *group of assets.*

Advantages of the RRM as suggested by Landis and Wiegers (1997) include: few assumptions are required; the impacts of ranking decisions upon the final outcome can be examined by quantifying uncertainties in rankings via a sensitivity analysis; rule driven approaches can be easily incorporated into the ranking system; and the rankings are testable hypotheses. Limitations in using the RRM are that the approach uses an additive model, although the effects of some threats may be multiplicative (Andersen et al 2004), and/or interactive, and threats and habitats are ranked on their relative likelihood of occurrence, as opposed to their relative consequence of occurrence (Walker et al 2001). Potential pitfalls of this approach include the possibility that end users may rely on the ranking system without validating the projected risks (Landis and Wiegers 1997). Additionally, the geographic extent of the habitat will influence the magnitude of the effects, particularly with different size populations (Hayes and Landis 2004), and variable distances between sources and effects will add complexity and so increase uncertainty.

This project focuses on the application of the RRM as a regional risk assessment tool at two scales: the Northern Tropical Rivers (51 risk regions); and the Daly River catchment (18 risk regions). The aim of the project was to test the utility of the RRM in assessing the impact of multiple pressures/threats on multiple ecological assets for the tropical rivers of northern Australia. Specific objectives to address this aim are:

- To determine ecological assessment endpoints based on stakeholder values.
- To develop conceptual models in conjunction with stakeholders in representing risk hypotheses at the two scales.
- To identify and create risk regions at the two scales.
- To collate and create relevant spatial data for input into the RRM.
- Characterise risk through rankings and total relative risk calculations produced by the RRM.
- Conduct sensitivity analyses and document uncertainty.

3.2 Relative Risk Model methodology

This section provides definitions of terms used in the semi-quantitative ecological risk assessment process adopted, the staged methodology applied to both the Northern Tropical Rivers and the Daly River catchment, and a summary of the spatial data used.

3.2.1 Definitions

It is important to precisely define components of the ecological risk assessment to reduce linguistic uncertainty. Following are some key definitions. The definitions of land use types are located in Appendix 1.

In Lukacs & Finlayson (2008), Dowe (2008) defined four groupings of riparian vegetation species for the tropical rivers region:

- *Obligate riparian species*- plants that occur exclusively in the riparian zones associated with creeks, rivers, lakes or lagoons.
- *Facultative riparian species*- plants that occur in the riparian zone, but are more common in other habitats.
- *Freshwater aquatic species*- plants that occur in freshwater systems, in either moving or free-standing water, and spend most of their life cycle in water, but does include species that can withstand periodic drying.
- *Mangrove species*- species that occur in saltwater or brackish water environments, fringing rivers, estuarine areas and coastal areas.

For the purpose of developing and applying the RRM we have taken the broad definition of riparian zones (Price and Lovett 2002; Dixon et al 2006) to define riparian vegetation communities (refer to Table 3.1).

Table 3.1 Definitions of terms used in the semi-quantitative ecological risk assessment.

Term	Definition
Riparian zones	Any land that adjoins or directly influences a body of water, including: the land immediately alongside small creeks and rivers, including the river bank itself; gullies and dips which sometimes run with water; areas surrounding lakes; and wetlands and river floodplains which interact with the river in times of flood. (Price and Lovett 2002:1).
Habitat	A group of ecological assets or entities at the regional scale. E.g. Tropical waterway-includes threatened aquatic species, riparian vegetation community
Risk region	Sub-area of the region being assessed. For the Northern Tropical Rivers the risk regions are defined based on river basins (catchments) and for the Daly River catchment risk regions are defined based on sub-catchments.
Land clearing	Clearing is defined as all areas where 'native' vegetation has undergone any land cover change due to removal by mechanical or chemical means, but not including the removal of vegetation by grazing animals (Northern Territory Government).

The RRM methodology adopted in this project is similar to that outlined in Walker et al (2001) and Obery and Landis (2002). The methodology includes the following steps, and the approach, as described by Landis and Weigers (2005), is shown in Figure 3.2:

1 Determining the Ecological Assessment Endpoints (assets) based on stakeholder input;

2 Describing the habitats to be examined;

3 Determining the sources of threats;

4 Creating a spreadsheet of the conceptual model for ranking purposes;

5 Identifying and creating risk areas;

6 Ranking of threats based on a 2-point scheme (0, 2, 4, 6);

7 Ranking of habitats based on the proportion of a particular habitat within a risk region;

8 Relative Risk Calculations;

9 Risk Characterisation; and

10 Sensitivity Analysis and Uncertainty Analysis.

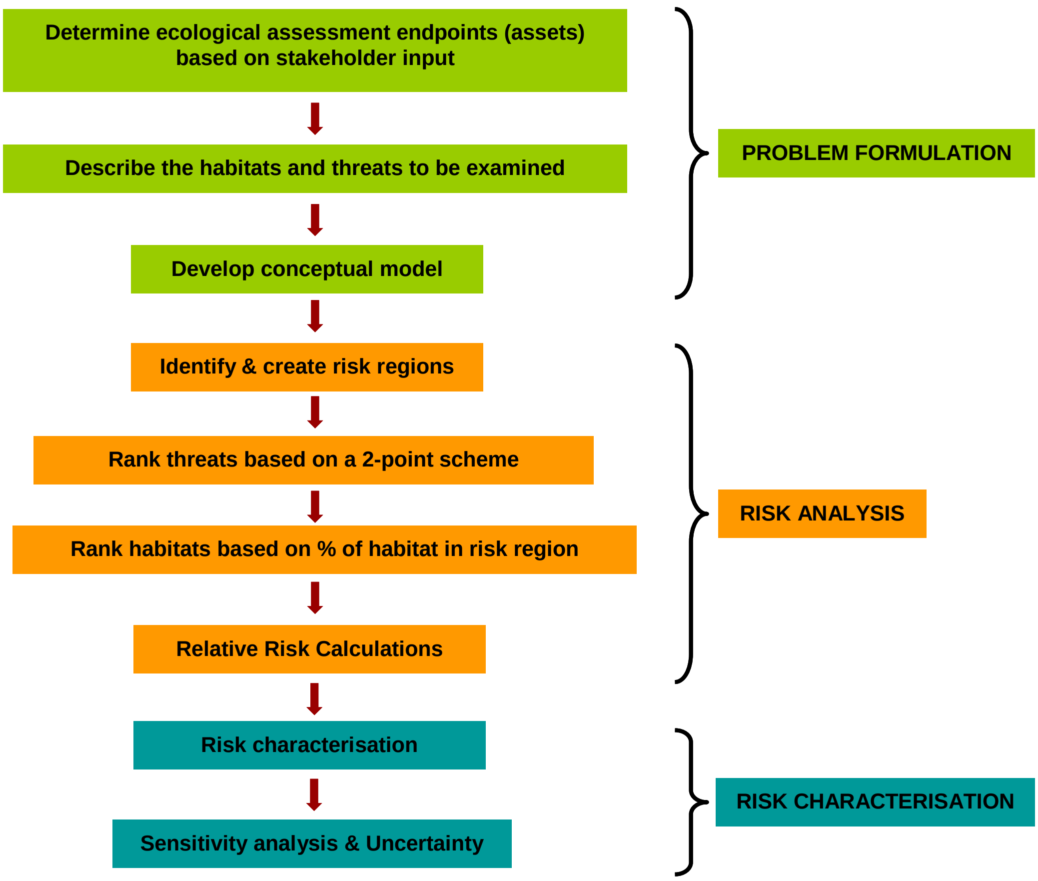


Figure 3.2 Flowchart of Relative Risk Model methodology

3.2.2 Problem Formulation

This component of the risk assessment involves the collation of existing information to determine the nature of the issue or problem.

The Risk Regions

Northern Tropical Rivers

The Northern Tropical Rivers study area includes the 51 river basins located in the north Australian coastal environment and which covers over 1 million km^2 as shown by Figure 3.3. The Northern Tropical Rivers encompass four jurisdictions (Western Australia, Northern Territory, Queensland and the Australian Federal Government). The streams located within the Northern Tropical Rivers can be categorised as being perennial, seasonal, dry seasonal, or seasonal-intermittent based on selected hydrological variables (Moliere et al 2006).

The complexities of land tenure and the increasing pressure on the region due to the impacts of the drought in the agricultural regions of southern Australia are detailed in Chapter 2.

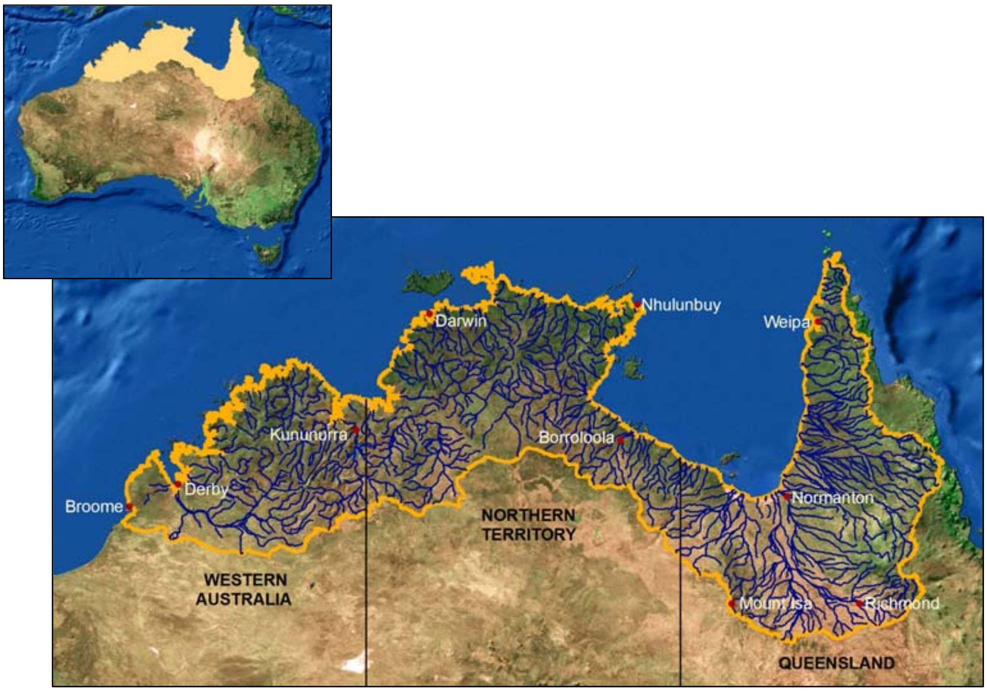


Figure 3.3 The Northern Tropical Rivers study area

Daly River Catchment

The Daly River Catchment is located in the 'Top End' of the Northern Territory. It encompasses approximately 52 600 km^2 and is one of the largest catchments in the Top End. The Daly River itself is one of the largest rivers in the Northern Territory (Faulks 1998) and has a perennial flow component. The major population centre within the catchment is Katherine and the dominant land use type is grazing of natural vegetation followed by traditional indigenous use (see Figure 3.4).

Chapter 2 provides a detailed description of land uses and ecological assets within the Daly River catchment.

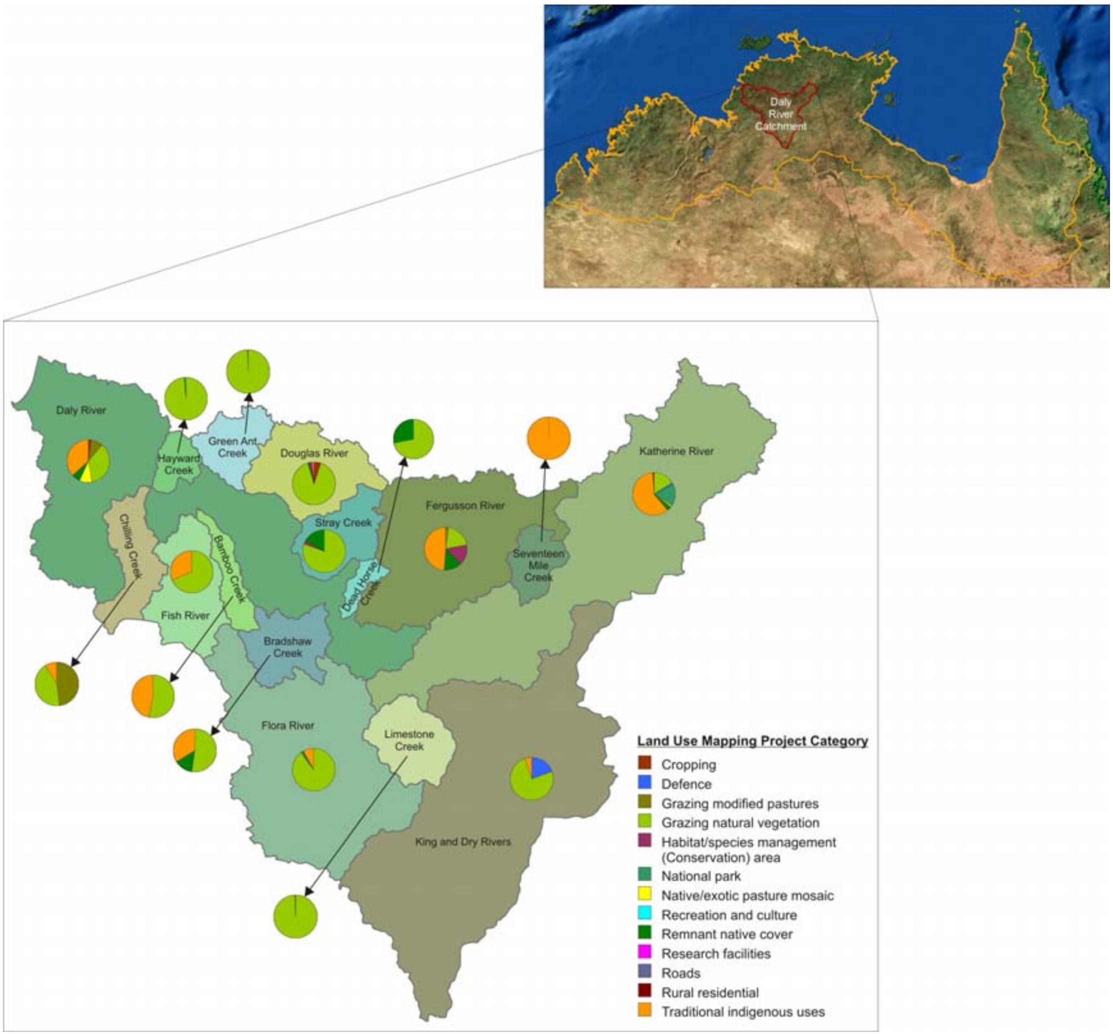


Figure 3.4 Daly River sub catchments and associated land use derived from the NT Government's Land Use Mapping Project data.

Ecological Assessment Endpoints

Ecological assessment endpoints are defined by the US EPA (1998:28) as 'explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes'.

The US EPA (1998) outlines the processes for selecting ecological assessment endpoints. In summary, the processes can be divided into two steps. The first step involves selecting ecological values that are suitable for assessment endpoints. There are three selection criteria in this process:

- Ecological relevance: ecological entities must currently, or historically, be part of the ecosystem, and changes in these endpoints can be quantified and identified at any functional organisation.
- Susceptibility to known or potential stressors: ecological entity's sensitivity to a stressor they are, or may be, exposed to.
- Relevance to management goals: selection of ecological value that meets both the requirements of scientific rigour and enhances the management decision process, thereby meeting the needs of environmental managers and stakeholders.

The second step specifically relates to defining the assessment endpoints. There are two components in defining the endpoints: (1) the identification of the specific ecological entity (eg species, functional group and habitat), and (2) selection of the characteristic of the ecological entity that requires protection from potential risks (eg nesting habitat).

In selecting ecological assessment endpoints for the two scales at which the RRM was applied, we used existing information gathered from previous stakeholder workshops and undertook a number of formal consultations with selected stakeholders for the Daly River catchment. Table 3.2 provides a list of publicly available reports and existing records of stakeholder meetings that were used in formulating assessment endpoints for the Northern Tropical Rivers study area and the Daly River catchment http://www.nt.gov.au/nreta/naturalresources/water/regions/dalyregion/crggroup.html

After synthesising information from the reports and records of stakeholder meetings we determined four ecological assessment endpoints for the Northern Tropical Rivers and five for the Daly River catchment (Table 3.3). The defined assessment endpoints for both RRM scales are similar. There is a further assessment endpoint defined for the Daly River catchment relating to maintenance of threatened aquatic species. This was due to the availability of sufficient information to identify and describe the value of threatened aquatic species for this system. There is a difference between the assessment endpoints referring to flow for the two scales, and this is due to the scale of the risk regions. The Daly River is not the only catchment that has a perennial flow component in tropical Australia. However, when examining the Northern Tropical Rivers as a whole, flow characteristics, dependencies and regime varies between catchments (Moliere et al 2006), and this variability is best captured at this broad scale as flow regime.

Habitats

A habitat is defined as a group of receptors at the regional level (Landis and Weigers 1997). As defined in Table 3.1, a habitat in this project is a group of ecological assets or entities at the regional scale.

Habitats were selected that are directly related to tropical rivers and that have spatial data that are readily accessible. These data sources are summarised further on in Tables 3.5 and 3.6. The three habitats selected for both RRM scales were:

- **Waterways –** defined as a natural channel along which water may flow from time to time with a minimum size criteria of 2 500 metres (GEODATA TOPO 250K).
- **Riparian vegetation** – vegetation communities that exist in the riparian zone as defined in Table 3.1.
- **Wetlands** – are defined in congruence with the Ramsar Convention (1971) except for the marine component ("marine water depth at which low tide does not exceed six metres"). The definition adopted in this project based on the Ramsar Convention (Article 1.1) includes (Ramsar Convention Secretariat 2006):

  "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt within the landward zone of the coastline."

Table 3.2 Publicly available reports and stakeholder meeting records used in formulating ecological assessment endpoints for the two RRM scales.

Northern Tropical Rivers study area	Daly River Catchment, NT
Cape York Peninsula Natural Resource Management Plan – Working draft for public consultation, 2004 (Cape York Interim Advisory Group)	Aquatic conservation values of the Daly River Catchment, Northern Territory, September 2005 (WWF)
Gulf draft water resource plan economic and social assessment report, 2006 (Department of Natural Resources and Water)	Draft Conservation Plan for the Daly Basin Bioregion, August 2003 (NT DIPE)
Northern Gulf region, Natural Resource Management Plan, September 2004 (McDonald GT & Dawson SJ)	Daly River Community Reference Group Draft Report, November 2004
Mitchell River Watershed Management Plan - A strategic and cooperative approach to managing the Mitchell River Watershed for a sustainable future, 2000 (Mitchell River Watershed Management Group)	Preliminary report on Aboriginal perspectives on land use and water management in the Daly River region, NT, 2004 (Jackson S)
Draft Gulf Water Resources Plan - Queensland Environment Groups' submission, 2005 (Queensland Environment Groups)	
Draft natural resource management strategy – rangelands region of Western Australia, 2005 (Rangelands Natural Resource Management Coordinating Group)	
The assets, threats and targets of the region. Book 4, Southern Gulf Catchments Natural Resource Management Plan., 2005 (Southern Gulf Catchments)	
Fitzroy river system: environmental values, 2001 (Storey AW, Davies PM and Froend RH)	
Ecological values of the Fitzroy River with links to indigenous cultural values. In Kimberley Appropriate Economies Roundtable Forum Proceedings, convened 11-13 October 2005 (Storey AW)	
Gulf and Mitchell water resource planning, Land and water assessment report, 2004 (Department of Natural Resources Mines and Energy)	

Table 3.3 Ecological assessment endpoints for the two RRM scales.

Northern Tropical Rivers study area	Daly River Catchment, NT
Maintenance of flow regime.	Maintenance of existing perennial flow.
Water quality to meet or exceed a specified standard.	Water quality to meet or exceed a specified standard.
Maintenance of extent and health of riparian vegetation.	Maintenance of threatened aquatic species.
Maintenance of biodiversity.	Maintenance of extent and health of riparian vegetation.
	Maintenance of biodiversity.

The spatial data used to represent wetland habitats according to the above definition were represented by the GEODATA TOPO 250K Series 3 dataset. The data are composed of the following features and sub-types:

- Flats
  - *Land subject to inundation* – Low lying land usually adjacent to lakes or watercourses, which is regularly covered with flood water for short periods.
  - *Marine swamp* – That low lying part of the backshore area of tidal waters, usually immediately behind saline coastal flat, which maintains a high salt water content, and is covered with characteristic thick grasses and reed growths.
  - *Saline coastal flat* – That nearly level tract of land between mean high water and the line of the highest astronomical tide.
  - *Swamp* – Land which is so saturated with water that it is not suitable for agricultural or pastoral use and presents a barrier to free passage.
- Lake - A naturally occurring body of mainly static water surrounded by land.
- Reservoirs
  - *Town Rural Storage* – A body of water collected and stored behind a constructed barrier for some specific use (with the exception of Flood Irrigation Storage).
  - *Flood Irrigation Storage* – A body of water collected and stored behind a constructed barrier for the specific use of Flood Irrigation Farming.
- Watercourse – A natural channel along which water may flow from time to time.
- Rapid Areas – An area of broken, fast-moving water in a watercourse, where the slope of the bed increases (but without a prominent break of slope which might result in a waterfall), or where the water passes an outcrop of harder rock.
- Pondage Areas
  - *Aquaculture Area* – Shallow beds, usually segmented by constructed walls, for the use of aquaculture.
  - *Salt Evaporator* – A flat area, usually segmented, used for the commercial production of salt by evaporation.
  - *Settling Pond* – Shallow beds, usually segmented by constructed walls, for the treatment of sewage or other wastes.
- Native Vegetation Areas
  - *Mangroves* – A dense growth of mangrove trees, which grow to a uniform height on mud flats in estuarine or salt waters. The land upon which the mangrove is situated is a nearly level tract of land between the low and high water lines.

Threats

The process for identifying threats was similar to that for defining ecological assessment endpoints (use of existing reports and government stakeholder input). Major threats to the ecological assessment endpoints identified at both scales were: land use; land clearing; potential sea level rise impacts; fire hazard; water regulation and extraction; mining; and weeds and feral animals. Inclusion of a threat in applying the RRM was based on whether or not there were spatial data of a suitable nature readily available (refer to Section 3.2.2.5).

Given the suitability of spatial datasets for application in the RRM approach we have undertaken, the following threats were included in the model:

Northern Tropical Rivers

Land use;

Potential sea level rise impacts;

Mining;

Fire hazard;

Feral animals (pigs); and

Weeds.

Daly River Catchment

Land use;

Land clearing;

Mining;

Potential sea level rise impacts; and

Fire hazard.

The potential impacts of these threats on the ecological assets of tropical rivers are comprehensively discussed in Chapter 2.

Table 3.4 provides a definition of each of the threats alongside their percentage areal cover at the two scales. Land use is further divided into secondary classes derived from the Australian Land Use and Management (ALUM) classification (Version 5 2001; Bureau of Rural Sciences 2002). These secondary classes include: cropping; grazing modified pastures; grazing natural vegetation; intensive animal production; intensive horticulture; irrigated agriculture; manufacturing and industrial; other minimal uses; production forestry; residential; services; transport and communications; utilities; and waste treatment and disposal. The amalgamation of the Land Use Mapping project (LUMP) spatial data, and the source of spatial data for each of the threats at the two scales, are discussed further on in this section.

Spatial data representing habitats and threats

This section describes the spatial data used as input into the RRM application. Spatial data used to represent pressures/threats and habitats for the Northern Tropical Rivers study area and Daly River risk region are outlined in Table 3.5 and Table 3.6, respectively.

Land Use Mapping data

Land use data were derived from catchment scale data (1:25,000-1:250,000) collected under the Australian Collaborative Land Use Mapping Program (ACLUMP). Land use data were selected from the following jurisdictional datasets across the TRIAP study area and for the Daly River catchment: Land Use in Queensland (1999); Land Use Mapping of the Northern Territory (2002); and Land Use in Western Australia (1997).

The catchment scale land uses are classified using the Australian Land Use and Management (ALUM) Classification (Version 5). The land use types listed in Tables 3.5 and 3.6 were extracted from the catchment scale data at the secondary class level. Definitions of the land uses and the ALUM Classification (Version 5) are presented in Appendix 1.

Table 3.4 Definition of spatial data used to represent threats and areal percentage of cover for both the Northern Tropical River study area and the Daly River Catchment.

Threat	Description	% of Daly River Catchment	% of Northern Tropical Rivers
Cropping	Land under cropping. Land under cropping at the time of mapping may be in a rotation system so that at another time the same area may be, for example, under pasture. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping can vary markedly over relatively short distances in response to change in the nature of the land and the preferences of the land manager. It may also change over time in response to market conditions. Fodder production, such as lucerne hay, is treated as a crop as there is no harvesting by stock.	0.5%	<0.5%
Fire Hazard	Measure of the frequency of high severity fires (>1000 kW).	N/A	N/A
Grazing modified pastures	Pasture and forage production, both annual and perennial, based on a significant degree of modification or replacement of the initial native vegetation. Land under pasture at the time of mapping may be in a rotation system so that at another time the same area may be, for example, under cropping. Land in a rotation system should be classified according to the land use at the time of mapping.	4.6%	<0.5%
Grazing natural vegetation	Land uses based on grazing by domestic stock on native vegetation with limited or no attempt at pasture modification. Some change in species composition will have occurred, but the structure of the native vegetation type will be essentially intact.	53.0%	67%
Intensive animal production	Agricultural production facilities such as feedlots and piggeries may be included as Tertiary classes.	<0.5%	<0.5%
Intensive horticulture	Intensive forms of plant production.	<0.5%	<0.5%
Irrigated agriculture	This class includes agricultural land uses where water is applied to promote additional growth over normally dry periods, depending on the season, water availability and commodity prices. It includes land that receives only one or two irrigations per year, as well as areas that rely on irrigation for much of the growing season. Land parcels should be assigned to this class if infrastructure for irrigation is located in the parcel, although the land may be temporarily unused or put to alternative uses such as livestock grazing.	<0.5%	<0.5%
Land clearing	Clearing is defined as all areas where 'native' vegetation has undergone any land cover change due to removal by mechanical or chemical means, but not including the removal of vegetation by grazing animals.	Daly Catchment: 4.93% Daly Basin: 10.9%	N/A

Table 3.4 (continued)

Threat	Description	% of Daly River Catchment	% of Northern Tropical Rivers
Manufacturing & Industrial	Factories, workshops, foundries, construction sites etc. This includes the processing of primary produce eg sawmills, pulp mills, abattoirs, etc.	<0.5%	<0.5%
Mining		NA	NA
Other minimal uses	Areas of land that are largely unused (in the context of the prime use) but may have ancillary uses. This may be the result of a deliberate decision by the manager or the result of circumstances. The land may be available for use but for various reasons remains 'unused'.	4%	6%
Production forestry	Commercial production from native forests and related activities on public and private land.	<0.5%	<0.5%
Residential	Land used for residential purposes.	<0.5%	<0.5%
Sea Level Rise	Wetland areas within tidal influence and below 1m in elevation	<0.5% <0.5% of wetland habitat	<0.5% 3.6% of wetland habitat
Services	Land allocated to the provision of commercial or public services resulting in substantial interference to the natural environment.	<0.5%	<0.5%
Transport & communications	Includes the following tertiary classes: airports /aerodromes; roads; railways; navigation & communication.	<0.5%	<0.5%
Utilities	Includes the following tertiary classes: *Electricity generation/transmission*- Coal-fired, gas-fired, solar-powered, wind powered or hydroelectric power stations, sub-stations, powerlines, etc *Gas treatment, storage and transmission* - Facilities associated with gas production and supply.	<0.5%	<0.5%
Waste treatment & disposal	Waste material and disposal facilities associated with industrial, urban and agricultural activities.	N/A	<0.5%
Weeds	A plant in the wrong place at the wrong time, usually an exotic species. May be classified as an environmental or agricultural weed.	N/A	N/A

A number of secondary classes were aggregated in applying the RRM. Irrigated plantation forestry, irrigated modified pastures, irrigated cropping, irrigated perennial horticulture and irrigated seasonal horticulture were aggregated into a class named ‘irrigated agriculture’. Perennial horticulture, seasonal horticulture and intensive horticulture were aggregated into a class named ‘horticulture’.

Table 3.5 Pressures/threats and habitats, measurement unit, GIS representation and source of data for spatial information used for the Northern Tropical Rivers study area

Pressure/Threat	Unit	GIS Representation	Source of Data
Land Uses: 1. Cropping 2. Grazing Modified Pastures 3. Grazing Natural Vegetation 4. Intensive Animal Production 5. Intensive Horticulture 6. Irrigated Agriculture 7. Manufacturing & Industrial 8. Other Minimal Uses 9. Production Forestry 10. Residential 11. Services 12. Transport & Communications 13. Utilities 14. Waste Treatment & Disposal	Hectares	Polygon	Extract of Land Use in Queensland (1999), Land Use Mapping of the Northern Territory (2002), Land Use in Western Australia (1997) datasets. This dataset contains land use classes allocated in accordance with the “Australian Land Use and Management Classification (ALUMC Version 5)”. Source: Queensland Department of Natural Resources and Mines, NT Department of Natural Resources Environment and the Arts, and Agriculture WA.
Fire	Frequency	Raster	Extract of the Australian national frequency of all fires for 1997-2006. Fire Affected Areas (FFAs) derived from NOAA AVHRR satellite imagery. FFAs for each calendar year are attributed with a value of 1 and all layers summed, creating a layer with values from 0-10. Source: Bushfires NT.
Mining	Frequency	Point	MINOCC (Queensland MINeral OCCurrence)-2005, Mineral Occurrence Database (MODAT) 2005, and MINEDEX 2005. Includes abandoned mine, mineral occurrence and prospect status. Source: Geological Survey of Queensland, Northern Territory Geological Survey, and Geological Survey of Western Australia.
Pigs	Hectares	Polygon	Landscape Health in Australia (2000). Extract of pigs from feral animal data. Density classes are: absent; occasional or localised; common and widespread; and abundant and widespread (there is also a ‘no data’ class). Source: Department of the Environment, Heritage, Water and the Arts.
Sea Level Rise	Hectares	Polygon	Dataset derived from Shuttle Radar Topography Mission (SRTM) 3 arc-seconds elevation data and GEODATA TOPO 250K Series 3 wetland data. Source: Geoscience Australia

Table 3.5 (continued)

Pressure/Threat	Unit	GIS Representation	Source of Data
Weeds	Hectares	Polygon	Landscape Health in Australia (2000). Extract of weeds that may impact waterways. Density classes are: absent; occasional or localised; common and widespread; and abundant and widespread (there is also a 'no data' class). Source: Department of the Environment, Heritage, Water and the Arts.
Habitat			
Riparian Vegetation Communities	Hectares	Polygon	Extract of Queensland National Vegetation Information System (NVIS) 2002, Northern Territory NVIS 2005, and Pre-European Vegetation-Western Australian (NVIS Complient Version) 2005. Source: Queensland Herbarium (Environmental protection Agency), NT Department of Natural Resources Environment and the Arts, and Western Australia Department of Agriculture.
Wetlands	Hectares	Polygon	GEODATA TOPO 250K Series 3 (the following feature classes: flats, lake, watercourse, reservoirs, rapid areas, pondage areas and native vegetation areas). Source: Geoscience Australia
Waterways	Km^2	Line	GEODATA TOPO 250K Series 3 Source: Geoscience Australia

Fire hazard data

The results of a study of 220 permanent plots in Litchfield, Nitmiluk and Kakadu national parks in the Northern Territory (Russell-Smith et al in press) reinforce the long held theory that the frequency of severe fires has by far the greatest adverse affect on floral species richness and plant numbers in all guilds, habits and size classes. A positive correlation was found between high frequencies of low severity fire affected vegetation (scorch height < 2m; Intensity < 1000 kW) and floral/structural diversity (Russell-Smith & Edwards 2006). Furthermore, analysis of the aerial photographic histories of these 220 plots was recently published by Russell-Smith and Edwards (2006), and they found that the proportion of late dry season fires (post-July) that were moderate to high severity was over 75% and, in contrast, only 3% of early dry season fires were of high severity.

Further analyses of late dry season fires and erosion (Russell-Smith et al 2006) of highly erodible northern Australian soils indicated that sites that burnt under late dry season conditions suffered nearly three times the net loss of soil compared to unburnt sites. Hence, the frequency of high severity fires adequately describes the greatest risk from fire to landscapes.

Table 3.6 Pressures/threats and habitats, measurement unit, GIS representation and source of data for spatial information used for the Daly River catchment.

Pressure/Threat	Unit	GIS Representation	Source of Data
Land Uses: 1. Cropping 2. Grazing Modified Pastures 3. Grazing Natural Vegetation 4. Intensive Animal Production 5. Intensive Horticulture 6. Irrigated Agriculture 7. Manufacturing & Industrial 8. Other Minimal Uses 9. Production Forestry 10. Residential 11. Services 12. Transport & Communications 13. Utilities	Hectares	Polygon	Extract of Land Use Mapping of the Northern Territory (2002). This dataset contains land use classes allocated in accordance with the "Australian Land Use and Management Classification (ALUMC Version 5)". Source: NT Department of Natural Resources Environment and the Arts
Fire	Frequency	Raster	Fire frequency data derived from MODIS satellite imagery. The fire frequency data are a composite of fire mapping for the years 2003 to 2006. Fire Affected Areas (FAAs) for each calendar year are attributed with a value of 1 (i.e. for this analysis they are not separated by month nor season) and all layers summed, creating a layer with values from 0 to 4. Source: Tropical Savannas CRC and Bushfires NT.
Land clearing	Hectares	Polygon	Extract of the NT Native Vegetation Clearing Dataset (2005). Source: Natural Resource Management Division, NT Department of Natural Resources Environment and the Arts.
Mining	Frequency	Point	Mineral Occurrence Database (MODAT) 2005. Includes abandoned mine, mineral occurrence and prospect status. Source: Northern Territory Geological Survey
Sea Level Rise	Hectares	Polygon	Dataset derived from Shuttle Radar Topography Mission (SRTM) 3 arc-seconds elevation data and GEODATA TOPO 250K Series 3 wetland data. Source: Geoscience Australia

Table 3.6 (continued)

Pressure/Threat	Unit	GIS Representation	Source of Data
Habitat			
Riparian Vegetation Communities	Hectares	Polygon	Extract of Northern Territory National Vegetation Information System (NVIS) 2005. Source: NT Department of Natural Resources Environment and the Arts
Wetlands	Hectares	Polygon	GEODATA TOPO 250K Series 3 (the following feature classes: flats, lake, watercourse, reservoirs, rapid areas, pondage areas and native vegetation areas). Source: Geoscience Australia
Waterways	Km^2	Line	GEODATA TOPO 250K Series 3 Source: Geoscience Australia

The fire hazard data at the Northern Tropical Rivers study area scale is based on the Australian national frequency of all fires dataset, which is a GIS composite of fire mapping for the years 1997–2006. Annual mapping is derived from day-time NOAA AVHRR satellite imagery with 1.1 x 1.1 km pixels. Fire Affected Areas (FAAs) for each calendar year are attributed with a value of 1 (i.e. for this analysis they are not separated by month nor season) and all layers summed, creating a layer with values from 0 to 10. The mapping is undertaken by the Remote Sensing Services Unit, Landgate, WA Government on behalf of their own agency the Australian Greenhouse Office, the Tropical Savannas Cooperative Research Centre and Bushfires NT.

Fire frequency data for the Day River catchment are a composite of fire mapping for the years 2003 to 2006. Fire Affected Areas (FAAs) for each calendar year are attributed with a value of 1 (iefor this analysis they are not separated by month nor season) and all layers summed, creating a layer with values from 0 to 4. Annual mapping is derived from day-time passes of Terra & Aqua MODIS satellite imagery using the 250 m channels (red & nir) and a time difference of usually 3 to 7 days, local knowledge and feedback from stakeholders. The mapping is undertaken by the Tropical Savannas Cooperative Research Centre in conjunction with the Northern Territory's rural fire agency Bushfires NT.

Land clearing data

Land clearing data (2005) were acquired from the NT Department of Natural Resources, Environment and the Arts (NRETA) for the Daly River catchment. The data were derived from Landsat satellite imagery spanning back to 1990, pastoral land records (1992), Bureau of Rural Science data (1990–1995) and Northern Territory government road and planning/development information.

Mining data

Three datasets sourced from the different jurisdictions were used in representing mining information across the Northern Tropical Rivers study area. For Western Australia, the mines and mineral deposits extract from MINEDEX was used to represent status categories as follows: care and maintenance; development, operation; proposed; and shut down. The MODAT (Mineral Occurrence Database) was used to represent mines and mineral deposits in the Northern Territory. The status categories represented in MODAT are: abandoned; mineral occurrence; operating; and prospect. For Queensland, MINOCC (Mineral Occurrence) was used to represent the following status categories: abandoned; care and maintenance; and operating.

Feral animal (pig) data

Data on density of pigs across the Northern Tropical Rivers study area were obtained from the feral animal dataset within the Landscape Health in Australia (2001) data. Density classes within the data are as follows: absent; occasional or localised; common and widespread; and abundant and widespread. This is a qualitative dataset based on expert knowledge from State and Territory land resource and nature conservation agencies (Morgan 2000).

Vulnerability to potential sea level rise data

Wetlands vulnerable to potential sea level rise data were derived from the spatial wetland dataset created as described previously, and broad application of a method used by Bayliss et al (1997). Bayliss et al (1997) determined areas that could be affected at three scales: the biophysical region (defined as all rivers draining into Van Diemen Gulf); the Alligator Rivers Region; and the Magela Creek floodplain.

Satellite imagery was used to delineate areas which may be affected by sea level rise at 1:500 000 at the biophysical regional scale in the Bayliss et al (1997) study. Analysis of the limits of the potential impact zone were determined through seasonal changes in vegetation patterning throughout the year. Those areas that could be potentially affected by a rise in sea level were identified as areas below 4 m in elevation. This approach to identifying potential affected areas is suitable for the scale of analysis required for the application of the RRM. However, it was outside the scope of this project to undertake such a detailed assessment at both the focus catchment and Northern Tropical Rivers scales.

Broad scale approaches in delineating sea level rise impact areas for northern Australia have also been undertaken by Preston et al (2006) using coastal zone elevation represented by a Digital Elevation Model (DEM) at two intervals: 0-5m; and 6-10m. However, it is unclear how these impact areas relate to the Intergovernmental Panel on Climate Change (IPCC) sea level rise projections.

In deriving wetlands vulnerable to sea level rise for input into the RRM, the following approach was taken based on the most recent IPCC sea level rise projections (CSIRO 2007). Global sea level is projected to rise 0.18-0.59 cm by 2100, however there are uncertainties associated with ice sheet flow. If flow rates were to increase linearly with global average temperature, the upper ranges of the projected sea level rise would increase by 10-20 cm. Beyond 2100, sea level rise may continue for centuries due to climate processes and feedbacks as follows:

- Thermal expansion would lead to an increase in seal level of 30–80 cm by 2300 (relative to 1980–1999); and
- If a negative surface mass balance for the Greenland ice sheet was sustained for thousands of years, the resulting elimination of the Greenland ice sheet would lead to a contribution in sea level rise of approximately 7m.

Given these projections, vulnerable wetlands in northern Australia were determined using Shuttle Radar Topography Mission (SRTM) elevation data. This dataset has been supplied at 3 arc-seconds, or 90 m, in the horizontal, and 16 m (absolute) vertical resolution. Wetlands data for the Northern Tropical Rivers study area and the Daly River catchment were clipped firstly to a 70 m buffer from the coast (average maximum tidal influence across the region) and then for both areas below 1 m and 7 m elevation within this buffer as shown in Figures

3.5 and 3.6, respectively. For input into the RRM, the wetlands below 1m were used as this is this most realistic area subject to vulnerability given the projections and in terms of natural resource management planning. The total area of wetlands below 1 m elevation across the Northern Tropical Rivers study area is approximately 27 867 km^2 (3.6% of wetland habitat across the 51 risk regions) and 3.34 km^2 for the Daly River (located in the Daly River Estuary risk region).

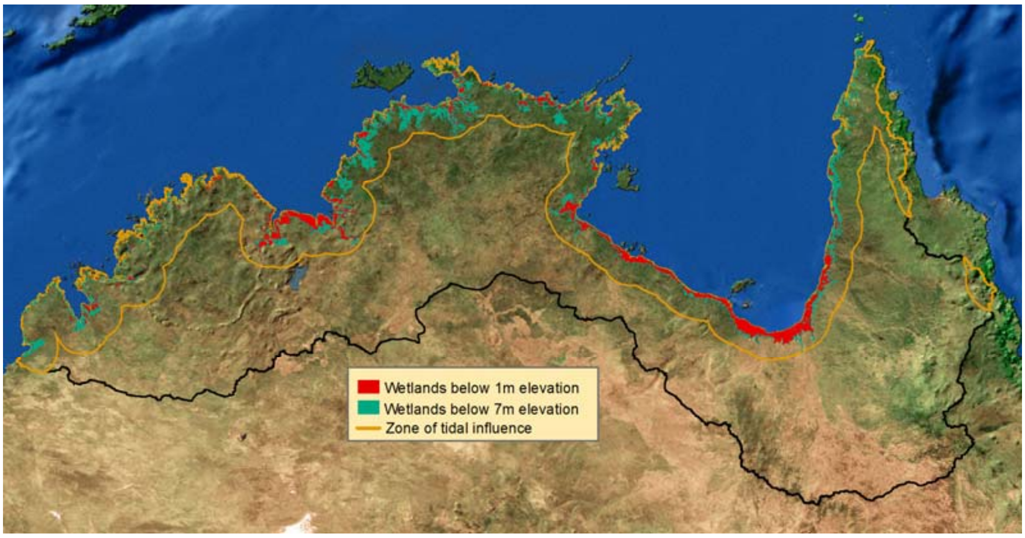


Figure 3.5 Wetlands vulnerable to potential sea level rise across northern Australia. See text for description of how this was derived.

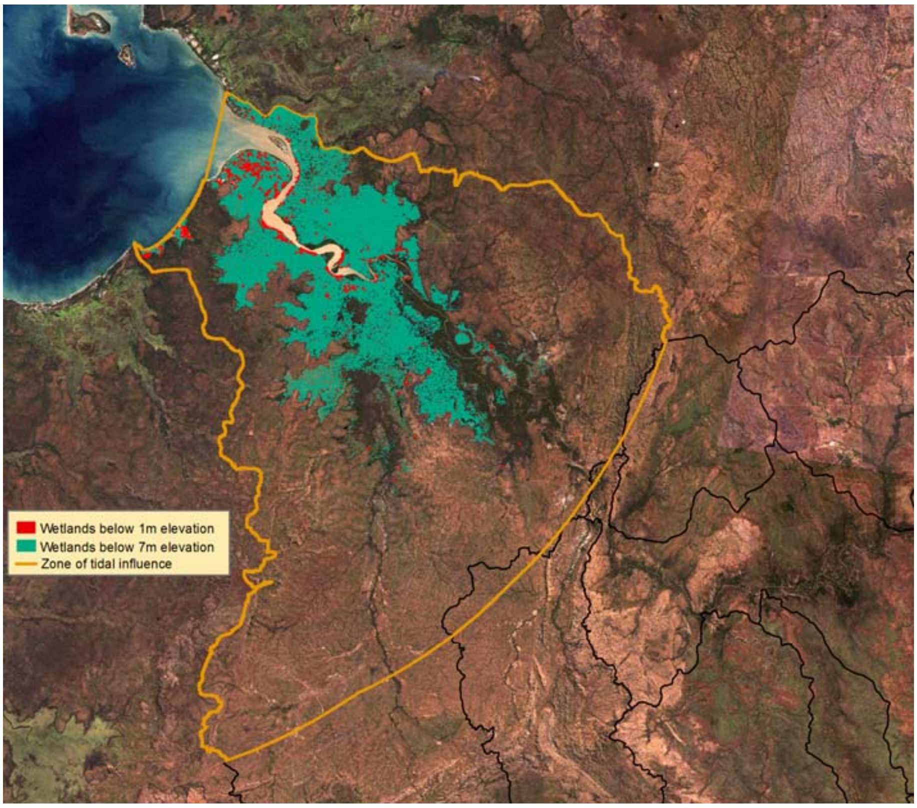


Figure 3.6 Wetlands vulnerable to potential sea level rise in the Daly River catchment. See text for description of how this was derived.

Weeds data

Data on density of Weeds of National Significance (WONs) across the Northern Tropical Rivers study area were obtained from the non-indigenous plant species (weeds) of national importance dataset within the Landscape Health in Australia (2001) data. Density classes within the data are as follows: absent; occasional or localised; common and widespread; and abundant and widespread. As with the feral animal (pig) datasets, this is a qualitative dataset based on expert knowledge from State and Territory land resource and nature conservation agencies (Morgan 2000).

The weeds deemed to be a threat to tropical waterways were extracted from the above dataset. The seven species included are:

- Pond Apple (Annona glabra);
- Cabomba (Cabomba caroliniana);
- Olive Hymenachne (Hymenachne amplexicaulis);
- Rubber vine (Cryptostegia grandiflora);
- Parkinsonia (Parkinsonia aculeata);
- Mesquite (Prosopis spp.); and
- Salvinia (Salvinia molesta).

Although a WON with a major impact on tropical wetlands, Mimosa (*Mimosa pigra*) was not included in this dataset and represents a major shortcoming. Similarly for the introduced para grass (*Urochloa mutica*), although not classified as a WON. Whilst para grass is a significant environmental weed it is also a highly valued pasture grass.

Weeds were not included in the Daly River catchment regional risk analysis as there were no suitable distribution maps available for the weeds listed above. There are some observational point data collected for some terrestrial habitats, however these have not been collected systematically and so could not be used in this risk assessment because a recorded absence may be due to lack of survey effort. The weed species of concern in the Daly River catchment are outlined in Chapter 2 (Section 2.2.3) and do not include mimosa and para grass on the floodplain as these are dealt with separately in Chapter 4 (Section 4.2.2) via a quantitative spatially-explicit ERA. Systematic and high resolution (5 km grid) distribution and abundance data for these two key floodplain weeds were obtained from helicopter surveys conducted by the NRETA Weeds Branch in 2003.

For the species listed above, systematic survey data need to be acquired across the catchment and, following this, predictive distribution maps (Habitat Suitability Models) need to be developed. Both these tasks require careful planning and considerable resourcing, and are necessary pre-requisites for spatially-based ecological risk assessments of regional weeds.

Wetlands spatial data

Data representing wetlands under the inventory sub-project of the TRIAP (Lukacs & Finlayson 2008) were sourced from the GEODATA TOPO 250K Series 2. In sourcing spatial data for the ecological risk assessment, the updated GEODATA TOPO 250K Series 3 was used. Table 3.7 summarises the differences between the Series 2 and Series 3 datasets. The GEODATA TOPO 250K Series 3 feature classes listed in Table 3.7 were used to represent wetlands in the application of the RRM (refer to Section 3.2.2).

Riparian vegetation habitats spatial data

The National Vegetation Information System (NVIS) was used as the spatial data source for representing riparian vegetation habitats at both the Northern Tropical Rivers and Daly River catchment scales. Riparian vegetation was extracted from the NVIS data as there is no pre-existing riparian dataset for northern Australia or the Daly River catchment.

The riparian vegetation communities for the Queensland component of the Northern Tropical Rivers study area using the 'environ' category are listed in Appendix 2. There are four NVIS datasets that contributed to the Queensland dataset.

The riparian vegetation communities were extracted from the Northern Territory NVIS 2005 data for the NT component of the Northern Tropical Rivers study area and the Daly River catchment using the 'environ' category as follows:

- Alluvial plains or confined to levees adjacent to larger river systems and on poorly drained depressions. Soils generally poorly drained and clayey.
- Associated with floodplains of water courses, heavy grey clay alluvial soils.
- Flat to gently sloping, low lying floodplains often with braided drainage lines. Heavy grey or brown clays.
- Floodplains of major rivers. Heavy black to grey cracking clays.
- Landward edges in upper tidal reaches of creeks and rivers where there is a high freshwater influence.
- Low woodland, drainage flats.
- Low woodland/open woodland, plains/reflect drainage fringe.
- Low woodland/open woodland, drainage flats.
- Open forest, floodplain proper.
- Open forest, floodplain fringes.
- Open forest, riparian/springs.
- Poorly drained sites fringing water courses or in drainage depressions.
- Springs throughout Top End.
- Woodland, drainage flats.
- Woodland, river, creekline.
- Woodland/open-forest, billabongs.
- Woodland/open-woodland, floodplain/sedgeland.

Table 3.7 Comparison between GEODATA TOPO 250K Series 2 and Series 3 data for representation of wetlands.

GEODATA TOPO 250 K Series 2 ‘Waterbodies’ Data			**GEODATA TOPO 250 K Series 3**			
Feature	**Description**	**Equivalent in Series 3**	**Feature Class**	**Feature Type (*Sub Type*)**	**Feature Type Definition**	**Equivalent in Series 2**
Lake	A naturally occurring body of mainly static water surrounded by land.	Lake	*Flats*	*Land Subject To Inundation*	Same as Series 2	Land Subject To Inundation
Land Subject To Inundation	Low-lying land usually adjacent to lakes or watercourses, which is regularly covered with flood water for short periods.	Flats- Land Subject To Inundation		*Marine Swamp*	Same as Series 2	Marine Swamp
Mangrove Flat	A nearly level tract of land between the low and high water lines vegetated with mangroves.	Native Vegetation Areas- Mangrove		*Saline Coastal Flat*	Same as Series 2	Saline Coastal Flat
Marine Swamp	The low-lying part of the backshore areas of tidal waters, usually immediately behind saline coastal flats, which maintains a high salt water content, and is covered with characteristic thick grasses and reed growths.	Flats- Marine Swamp		*Swamp*	Same as Series 2	Swamp
Rapid	An area of broken, fast-moving water in a watercourse, where the slope of the bed increases (but without a prominent break of slope which might result in a waterfall), or where the water passes an outcrop of harder rock.	Rapid Areas	*Lake*		Same as Series 2	Lake
Reservoir	A body of water collected and stored behind a constructed barrier for a specific use.	Reservoirs- Town Rural Storage Reservoirs- Flood Irrigation Storage	*Reservoirs*	*Town Rural Storage*	A body of water collected and stored behind a constructed barrier for some specific use (with the exception of Flood Irrigation Storage).	Reservoir

Table 3.7 (continued)

GEODATA TOPO 250 K Series 2 'Waterbodies' Data			GEODATA TOPO 250 K Series 3			
Feature	**Description**	**Equivalent in Series 3**	**Feature Class**	**Feature Type (*Sub Type*)**	**Feature Type Definition**	**Equivalent in Series 2**
Saline Coastal Flat	The nearly level tract of land between mean high water and the line of the highest astronomical tide.	Flats-Saline Coastal Flats		*Flood Irrigation Storage*	A body of water collected and stored behind a constructed barrier for the specific use of Flood Irrigation Farming	Reservoir
Salt Evaporator	A flat area, usually segmented, used for the commercial production of salt by evaporation.	Pondage Areas-Salt Evaporator	*Watercourse*		Same as Series 2	Watercourse
Settling Ponds	Shallow beds, usually segmented by constructed walls, for the treatment of sewerage or other wastes, or for aquaculture.	Pondage Areas-Settling Pond	*Rapid Areas*		Same as Series 2	Rapid
Swamp	Land which is so saturated with water that it is not suitable for agricultural or pastoral use, and presents a barrier to free passage.	Flats-Swamp	*Pondage Areas*	*Aquaculture Area*	Shallow beds, usually segmented by constructed walls, for the use of aquaculture.	Pondage Area- Settling Pond
Water Body Void	A void area in a water body feature created by an inland island.	NIL		*Salt Evaporator*	Same as Series 2	Pondage Area- Salt Evaporator
Watercourse	A natural channel along which water may flow from time to time.	Watercourse		*Settling Pond*	Shallow beds, usually segmented by constructed walls, for the treatment of sewage or other wastes.	Pondage Area- Settling Pond
			Native Vegetation Areas	*Mangrove*	A dense growth of mangrove trees, which grow to a uniform height on mud flats in estuarine or salt waters. The land upon which the mangrove is situated is a nearly level tract of land between the low and high water lines.	Mangrove Mangrove Flat

The riparian vegetation communities were extracted from Western Australia NVIS data for the WA component of the Northern Tropical Rivers study area using the ‘broad floristic structure’ category and proximity to drainage as the ‘environ’ category referred to regional categories rather than an environmental attribute. The ‘broad floristic structure’ categories extracted to represent riparian vegetation are:

- *Aristida* mid open tussock grassland
- *Astrebla* (mixed) mid tussock grassland
- *Astrebla* mid tussock grassland
- *Chrysopogon* (mixed) mid tussock grassland
- *Chrysopogon* mid tussock grassland
- *Chrysopogon/Bothriochloa* mid tussock grassland
- *Chrysopogon/Dichanthium* mid tussock grassland
- *Dichanthium/Chrysopogon* mid tussock grassland
- *Enneapogon/Triodia* mid tussock grassland
- *Eucalyptus* low woodland
- *Eucalyptus* mid open woodland
- *Eucalyptus* mid woodland
- *Eucalyptus/Melaleuca* low woodland
- *Eucalyptus/Terminalia* mid woodland
- *Iseilema/Dactyloctenium* mid tussock grassland
- *Melaleuca* tall open shrubland
- *Melaleuca* tall shrubland
- *Sorghum* tall tussock grassland

Waterways spatial data

Data representing waterways (drainage) under the inventory sub-project of the TRIAP were sourced from the GEODATA TOPO 250K Series 2. In sourcing spatial data for the ecological risk assessment, the updated GEODATA TOPO 250K Series 3 was used.

3.2.3 Conceptual models

Conceptual models (as discussed in Chapter 1, Section 1.3.3) are the output of the problem formulation component of an ERA. Suter (1996) stated that “All screening and baseline ecological risk assessments should use and present a conceptual model”.

Conceptual models provide a written description and a diagram of relationships between pressures/threats and the ecological assets that may be affected. The models can present many relationships (US EPA 1998). In generating the conceptual models in this project, information from Chapter 2 and stakeholder input were incorporated. Some of the benefits of developing conceptual models as listed by the US EPA (1998) include:

- Provides a powerful communication tool representing the understanding of how a system functions enabling others to evaluate this understanding; and

- The models are readily modified as knowledge from stakeholders and experts in this instance is incorporated.

Risk hypotheses are illustrated in a conceptual model for the specified threats and habitats. The resultant conceptual model for the Northern Tropical Rivers study area, shown in Figure 3.7, formed the basis for undertaking risk calculations within the RRM for this region as outlined by Walker et al (2001). The risk hypotheses are evident through the links between threats, habitats and assessment endpoints, while the interactions are defined by the exposure and effects pathways.

In developing the conceptual model for the Northern Tropical Rivers study area, two stakeholder workshops were held: one in Derby, Western Australia, focussed on the Fitzroy River catchment; and one in Richmond, Queensland, focussed on the Flinders River catchment. A stakeholder workshop with the wider community was not held in the Northern Territory (specifically the Daly River catchment) as the stakeholders views are represented in the DRCRG Draft Report (DRCRG 2004) and these stakeholders had undergone a number of previous consultations. Conceptual models were developed at the Fitzroy River and Flinders River stakeholder workshops and reported by Bartolo (2006a,b). These models were further refined for input into the RRM by including information from the various Natural Resource Management Plans available across northern Australia (see Chapter 2 for details).

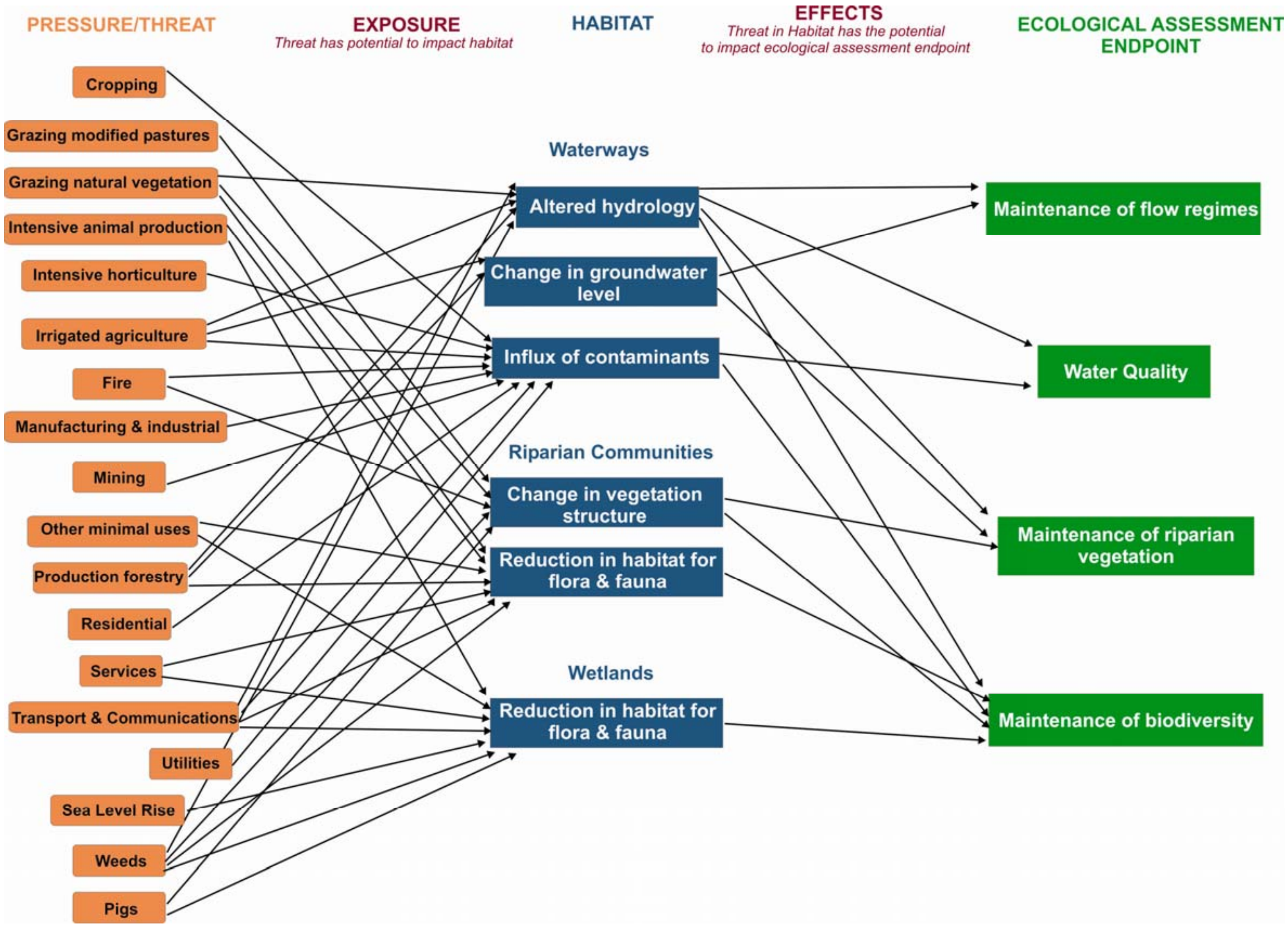


Figure 3.7 Conceptual model describing ecological risk for the Northern Tropical Rivers study area.

The Northern Tropical Rivers study area risk hypotheses related to ecological values only. Figure 3.7 shows the risk hypotheses associated with multiple land uses (as outlined above), altered fire regime, sea level rise, weeds and feral pigs with respect to their potential to alter hydrology, produce a change in groundwater level, result in an influx of contaminants, change riparian vegetation structure, and reduce habitat for flora and fauna in both riparian and wetland habitats. Land clearing was omitted from the conceptual model as there were no suitable spatial data available across northern Australia to include this pressure/threat in the conceptual model for input into the RRM.

The following is a risk hypothesis for residential pressure (which refers to urban development and human settlement). The consequence of residential pressure is the potential for an influx of contaminants into waterways (see Chapter 2). This may result in a degradation in water quality and a reduction in biodiversity.

Existing conceptual models were used as an initial basis for generating the conceptual model for input into the Daly River catchment RRM. Four risks to ecological sustainability were identified by the DRCRG (2004). For three of these risks (loss of perennial stream flow, sedimentation of the river and habitat degradation), conceptual models published by the DRCRG (2004) were used to draft a combined model. The DRCRG conceptual models for loss of perennial stream flow, sedimentation of the river and habitat degradation are shown in Figures 3.8–3.10, respectively.

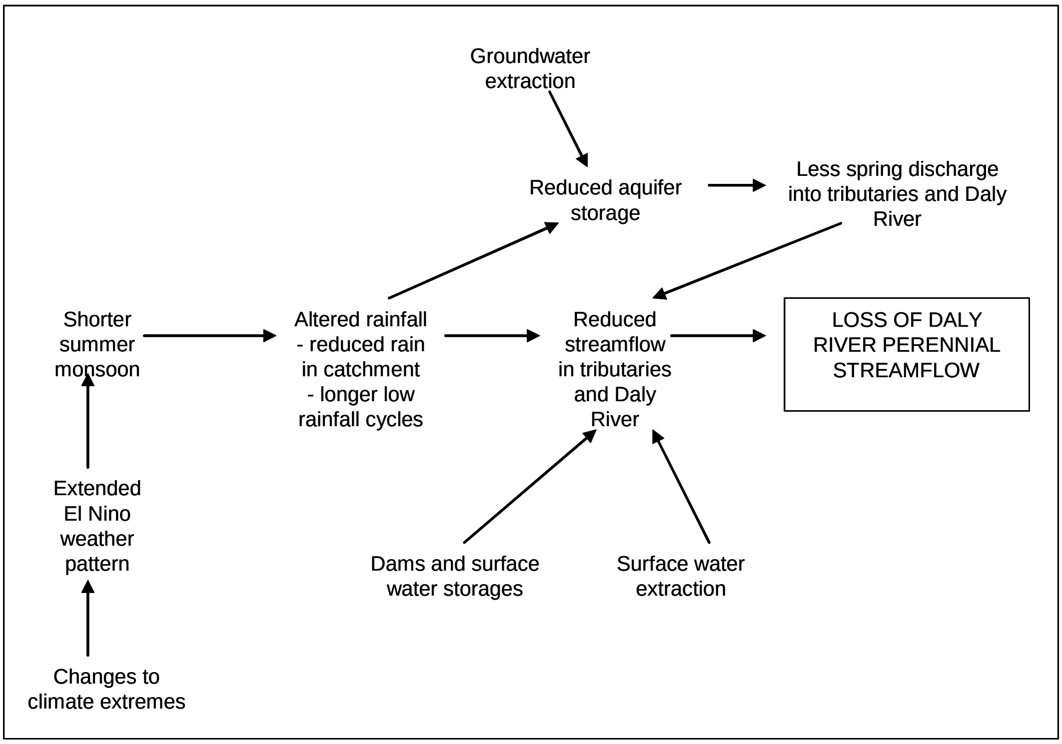


Figure 3.8 Conceptual model of the loss of perennial stream flow for the Daly River (DRCRG 2004:80)

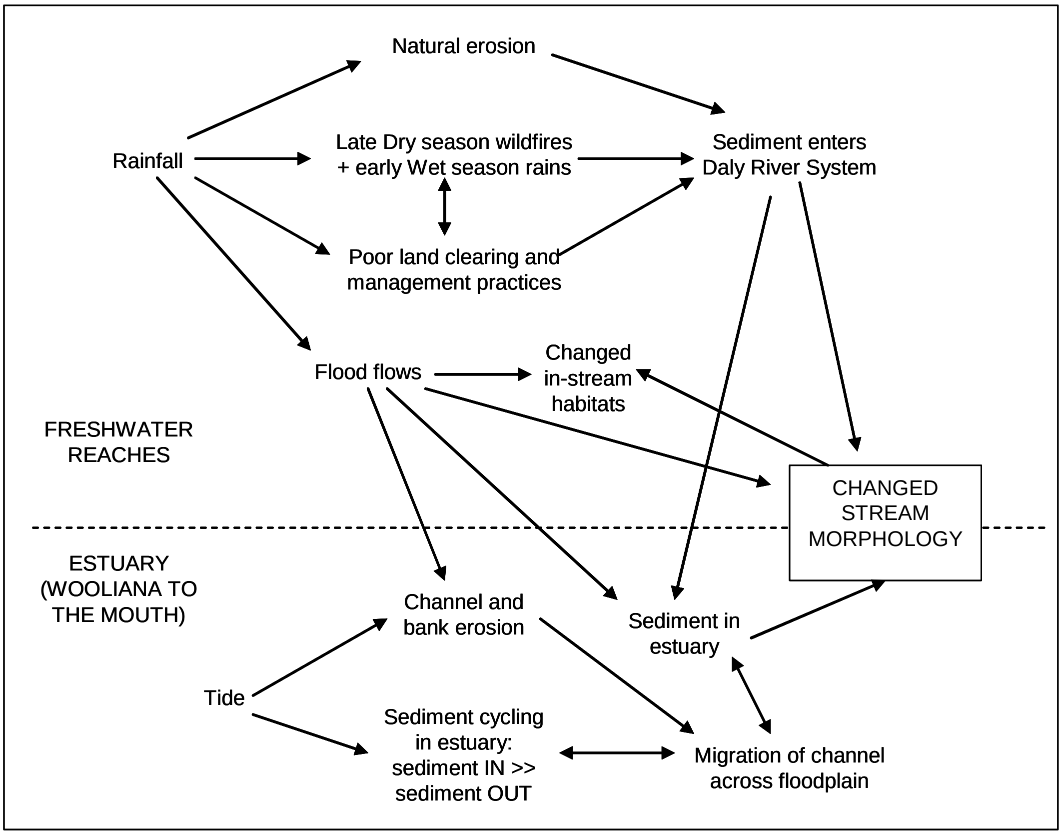


Figure 3.9 Conceptual model of sedimentation for the Daly River (DRCRG 2004:83)

In order to produce a conceptual model that combined the various pressures/threats and effects, a workshop was convened comprising university and government technical and resource management stakeholders familiar with the Daly River catchment. The output of this workshop was the conceptual model shown in Figure 3.11. This conceptual model was then simplified for application of the RRM based on the availability of spatial data referred to in Figure 3.12.

The Daly River catchment risk hypotheses were also based on ecological values. Figure 3.12 shows the risk hypotheses associated with multiple land uses (as outlined above), altered fire regime, land clearing and sea level rise and their potential to alter hydrology, produce a change in groundwater level, result in an influx of contaminants, change riparian vegetation structure, and reduce habitat for flora and fauna in both riparian and wetland habitats. Threats from weeds and feral animals were omitted from the conceptual model as there were no suitable spatial data available across risk regions based on sub-catchment to include them in the conceptual model for input into the RRM.

The following describes two examples of risk hypotheses from the Daly River catchment conceptual model. The first example is the impact of sea level rise on maintenance of biodiversity. The consequence of sea level rise is the decline of freshwater coastal wetlands (Winn et al 2006; Cobb et al 2007), resulting in a reduction in wetland habitat available for flora and fauna (Bartolo et al 2007). A reduction in wetland habitat may lead to a reduction in biodiversity, thereby impacting on the biodiversity assessment endpoint. The second example is the impact of altered fire regime (more frequent late dry season fires) on water quality, maintenance of riparian vegetation and biodiversity. Late dry season fires can result in an influx of contaminants through soil erosion and sedimentation (Russell-Smith et al 2006) and a change in riparian vegetation structure. An influx of contaminants through sedimentation will have an impact on water quality and biodiversity assessment endpoints. A change in riparian vegetation structure may result in an associated change in vegetation composition, impacting both the maintenance of riparian vegetation and the maintenance of biodiversity assessment endpoints.

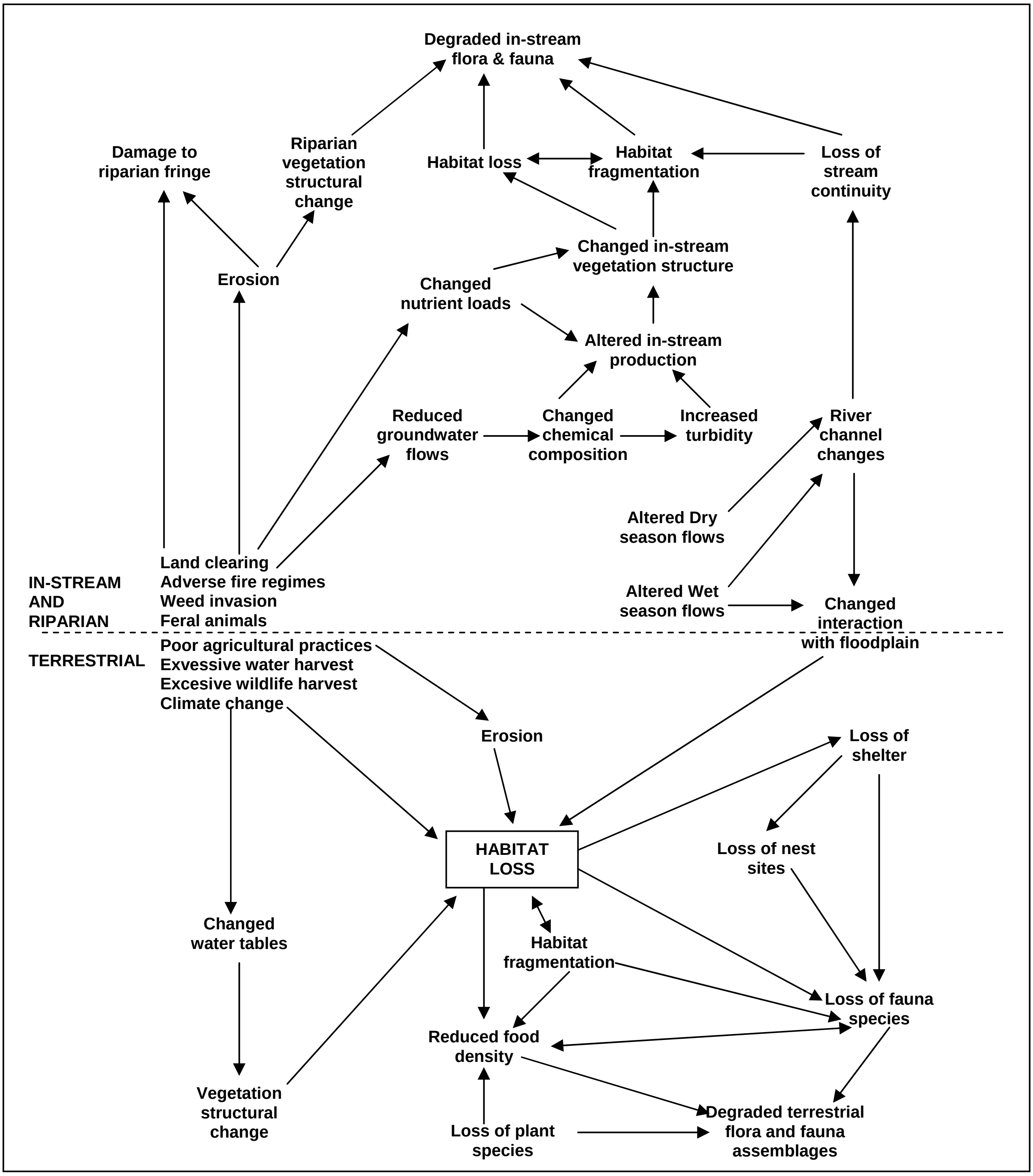


Figure 3.10 Conceptual model of habitat degradation for the Daly River (DRCRG 2004:85)

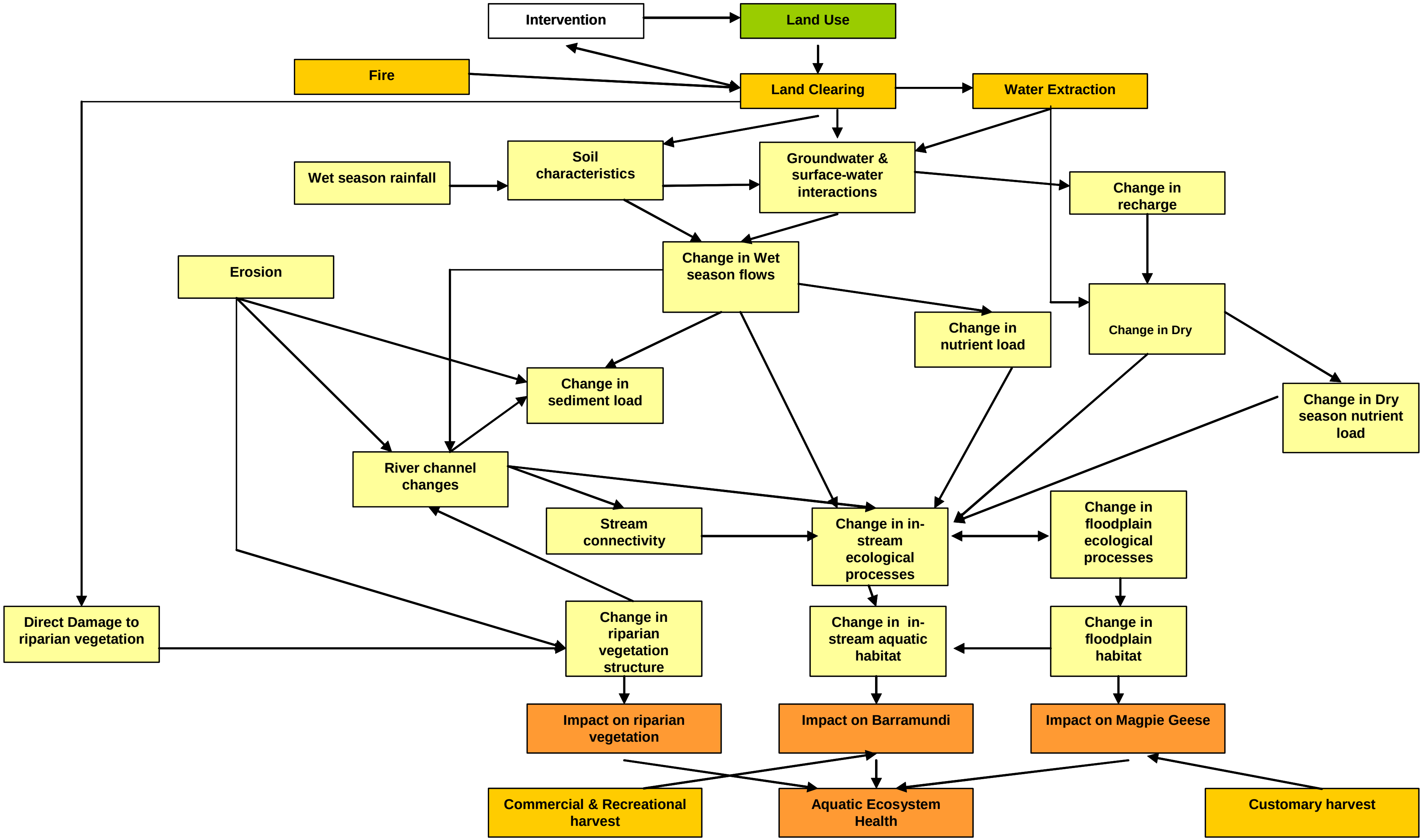


Figure 3.11 Conceptual model output from science and government stakeholder workshop describing ecological risk for the Daly River catchment

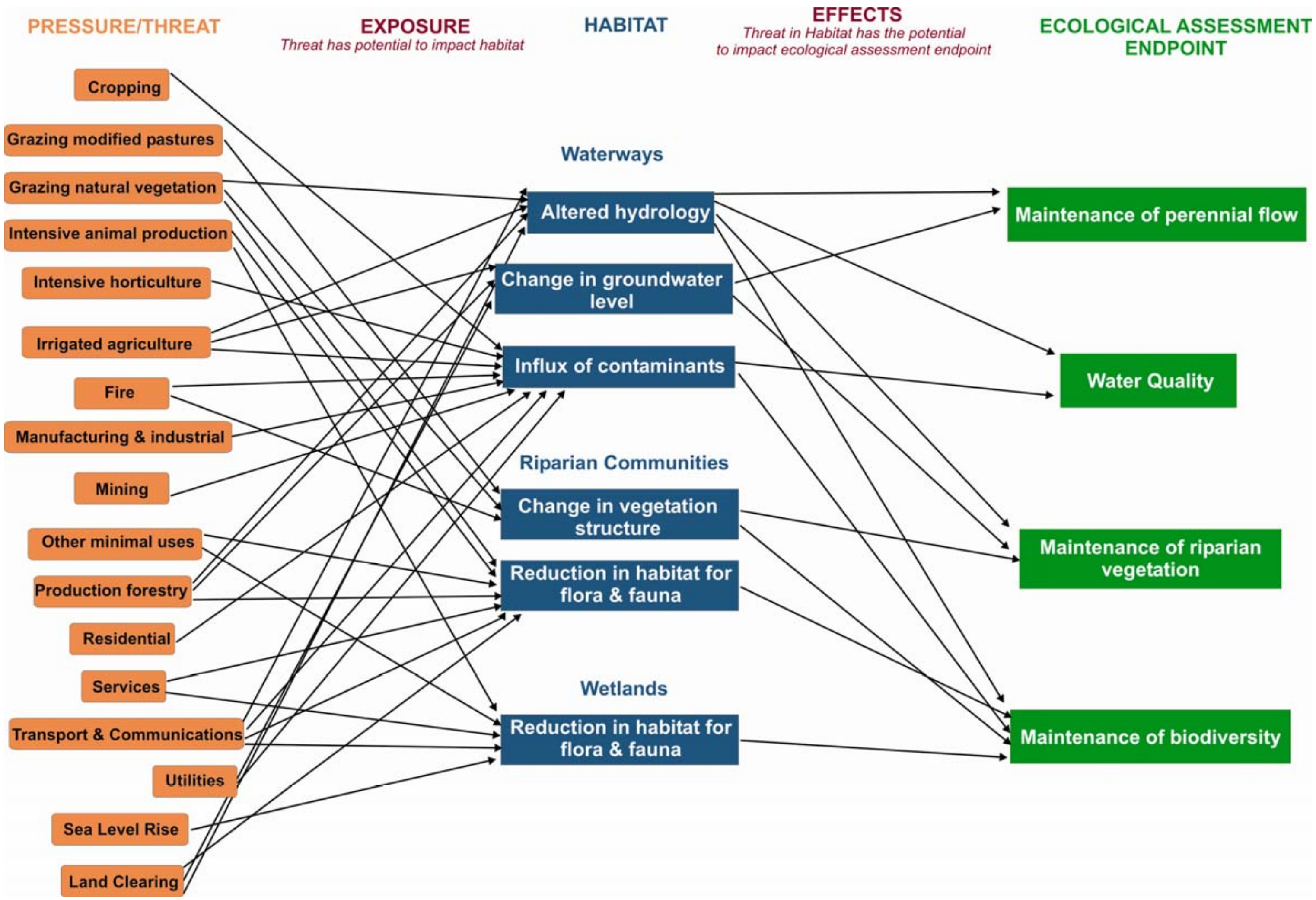


Figure 3.12 Final conceptual model describing ecological risk for the Daly River catchment

3.2.4 Risk Analysis

There were a number of iterations of the RRM for both the Northern Tropical Rivers study area and the Daly River catchment as the conceptual models were refined and more spatial data were incorporated. In conducting the sensitivity analysis component (see Section 3.5), earlier versions of the RRM outputs not reported here were used. The application of sensitivity analysis in this instance was to demonstrate the use of sensitivity analysis tools rather than testing the output of the RRM reported here.

Identifying and creating risk regions

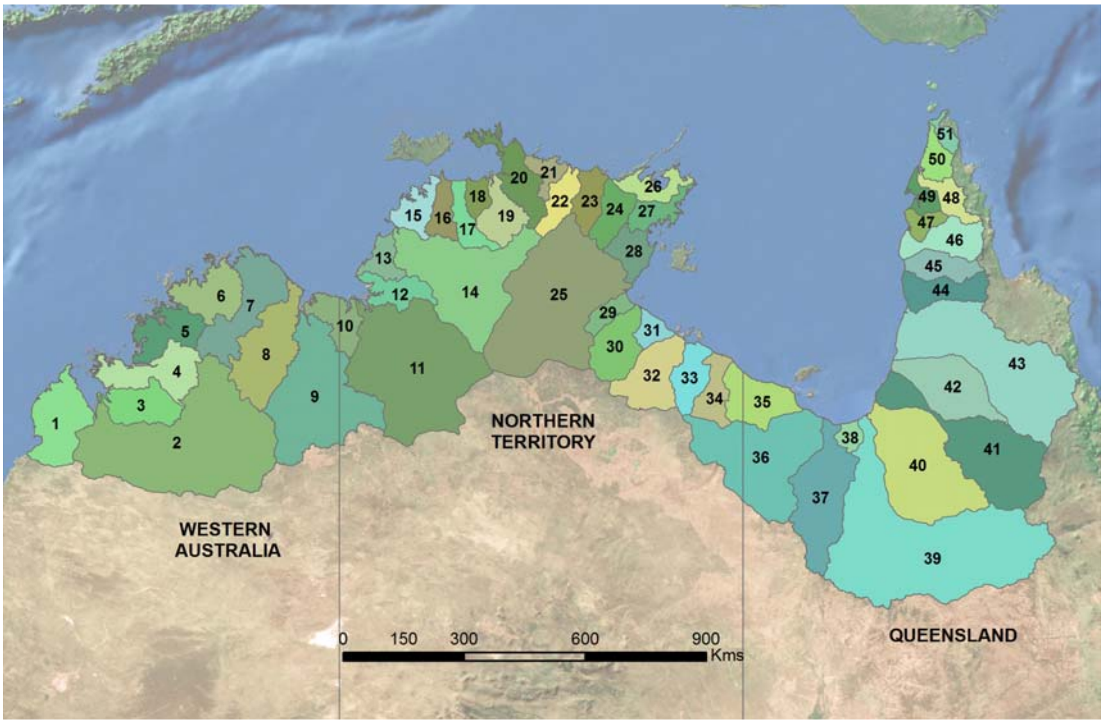
Fifty one (51) risk regions were identified for the Northern Tropical Rivers study area as shown by Figure 3.13. These risk regions are based on the river basins of the region as the ecological risk assessment is focused on ecological assets of tropical rivers. The size of the risk regions is shown in Figure 3.14.

For the Daly River catchment analysis we defined the following 18 risk regions (Figure 3.15): 1- Daly River; 2- Hayward Creek; 3- Green Ant Creek; 4- Douglas River; 5- Stray Creek; 6- Dead Horse Creek; 7- Fergusson River; 8- Seventeen Mile Creek; 9- Katherine River; 10- King and Dry Rivers; 11- Limestone Creek; 12- Flora River; 13- Bradshaw Creek; 14- Bamboo Creek; 15- Fish River; 16- Chilling Creek; 17- Daly River Estuary; and 18- Upper Katherine River.

Sixteen of the risk regions are delineated by 16 sub-catchment units defined by hydrological characteristics. A further two risk regions, the Daly River Estuary (17) and Upper Katherine River (18), were derived from risk regions Daly River (1) and Katherine River (9), respectively. These two risk regions were re-defined based on hydrological subsections of the sub-catchments and were both morphologically distinct units compared with the entirety of their sub-catchment. Figure 3.16 shows the size (hectares) of the risk regions.

Ranking threats and habitats

In the risk analysis, a two point scale (ie. 0, 2, 4, 6; corresponding to nil, low, medium, high, respectively) was implemented to categorise the percentage cover of a particular threat within each risk region. The two point scale values were assigned using Jenk's Optimisation (Jenks and Caspall 1971), which is a suitable method for clustering numerical data (Obery and Landis 2002). Jenk's Optimisation is also referred to as 'natural breaks' and is a common data classification algorithm procedure in GIS software. Break points are identified by grouping similar values in the data whilst maximising the differences between classes. Classes are automatically generated (the user selects the number of classes) in GIS software when applying natural breaks where class boundaries relate to relatively large jumps in data values. In applying Jenk's Optimisation in ranking habitats and threats, the number of classes were set at four to account for nil (0), low (2), medium (4) and high (6). The first class (nil) was manually set to zero (0). Results of the application of Jenk's Optimisation in ranking habitat and threats are shown in the Results section (Tables 3.10 and 3.12).



1	Cape Leveque Coast	14	Daly River	27	Koolatong River	40	Norman River
2	Fitzroy River	15	Finniss River	28	Walker River	41	Gilbert River
3	Lennard River	16	Adelaide River	29	Towns River	42	Staaten River
4	Isdell River	17	Mary River	30	Limmen Bight River	43	Micthell River
5	Prince Regent River	18	Wildman River	31	Rosie River	44	Coleman River
6	King Edward River	19	South Alligator River	32	McArthur River	45	Holroyd River
7	Drysdale River	20	East Alligator River	33	Robinson River	46	Archer River
8	Pentecost river	21	Goomadeer River	34	Calvert River	47	Watson River
9	Ord River	22	Liverpool River	35	Settlement Creek	48	Wenlock River
10	Keep River	23	Blyth River	36	Nicholson River	49	Embley River
11	Victoria River	24	Goyder River	37	Leichhardt River	50	Ducie River
12	Fitzmaurice river	25	Roper River	38	Morning Inlet	51	Jardine River
13	Moyle River	26	Buckingham River	39	Flinders River		

Figure 3.13 The fifty one (51) risk regions identified for the Northern Tropical Rivers study area

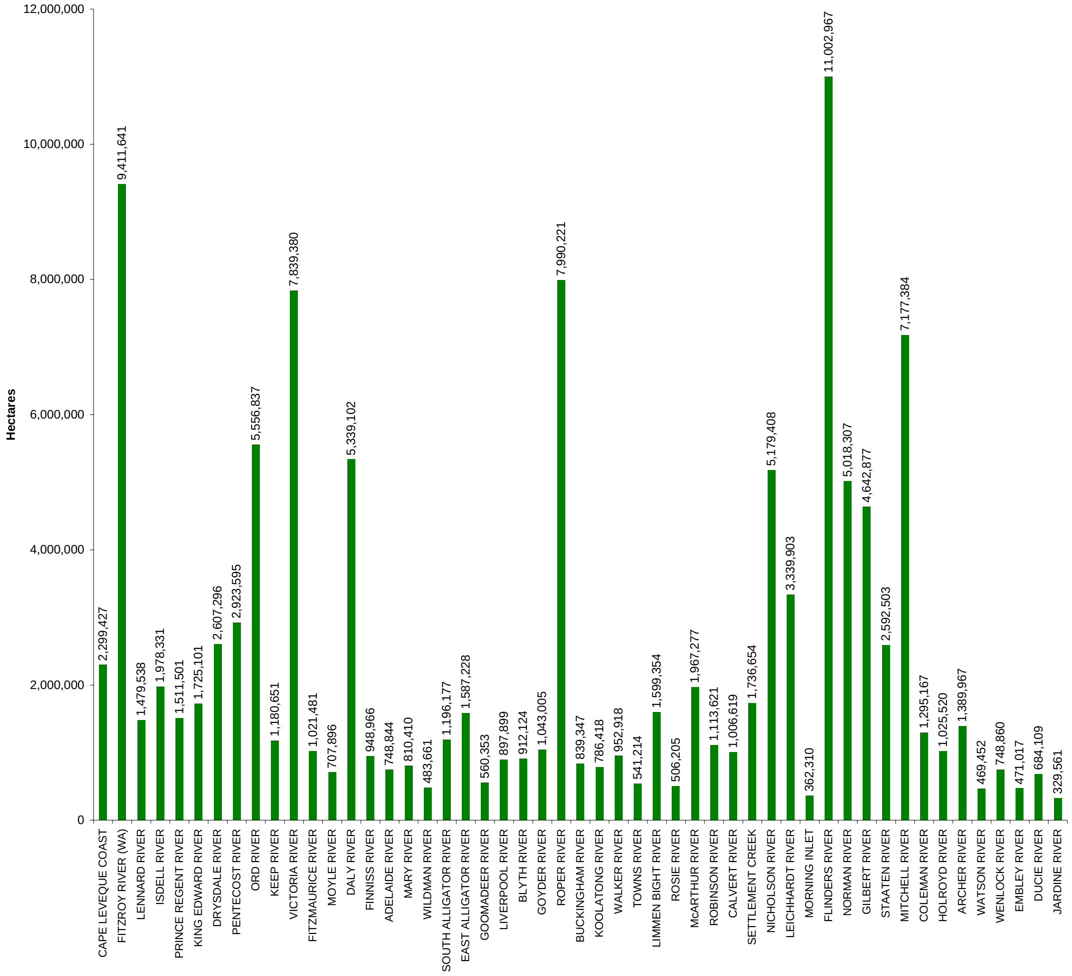


Figure 3.14 Areal size of the 51 risk regions identified for the Northern Tropical Rivers study area

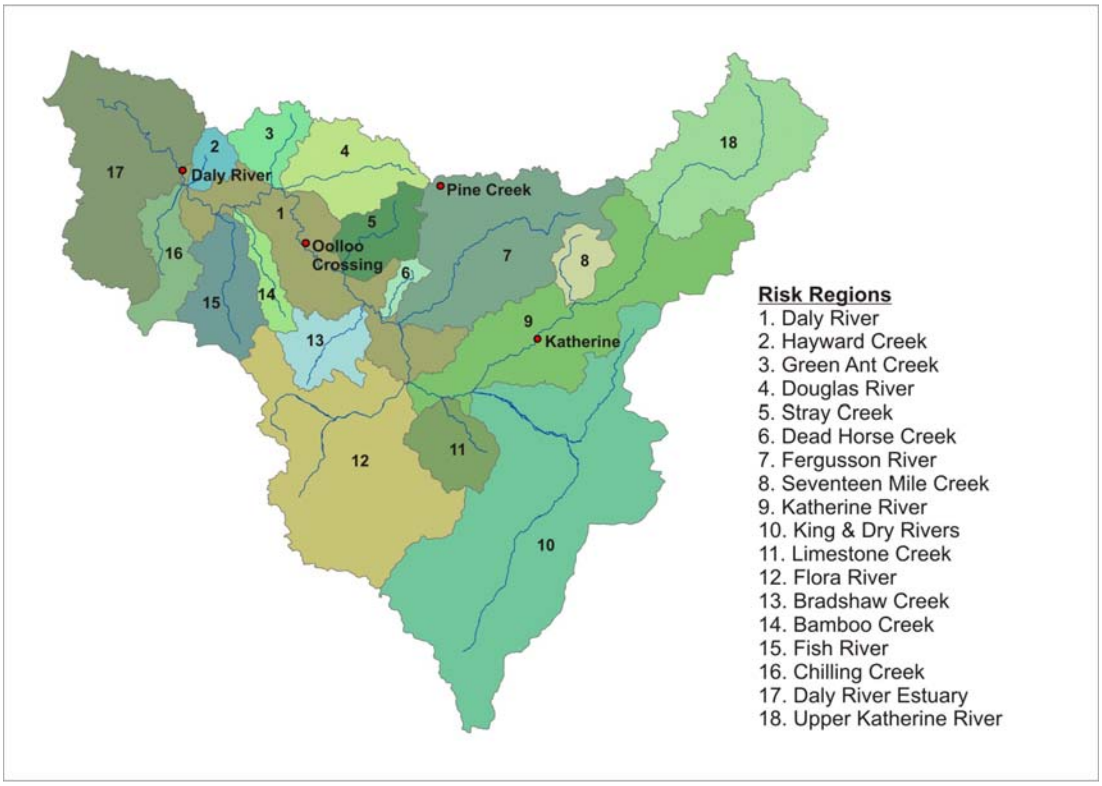


Figure 3.15 The eighteen (18) risk regions identified for the Daly River catchment

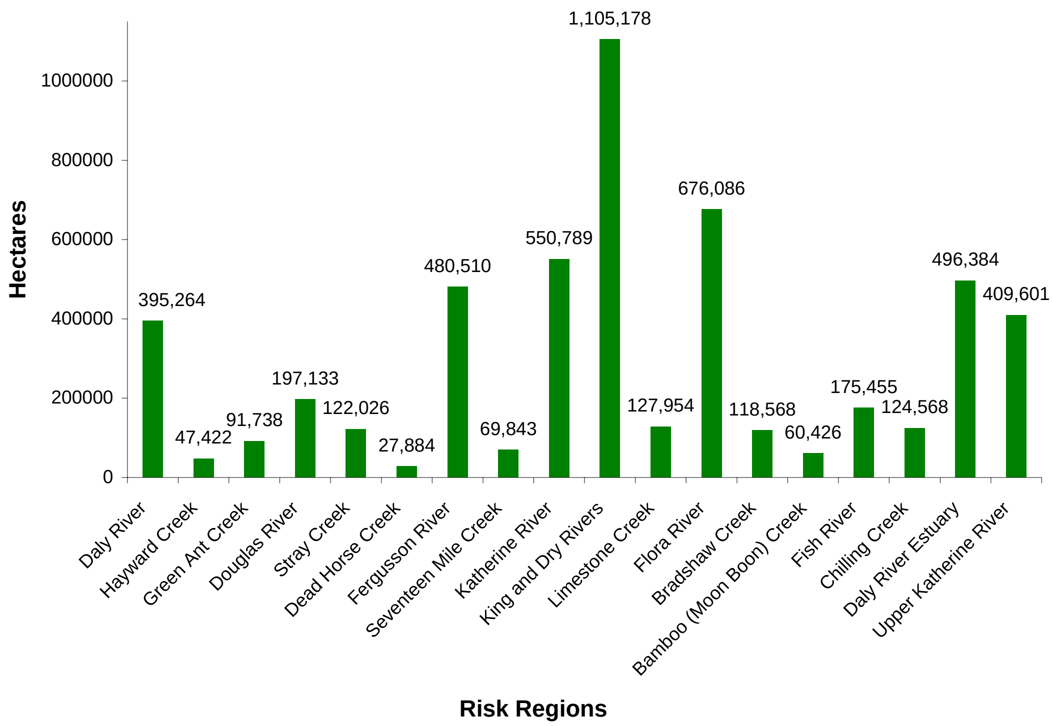


Figure 3.16 Areal size of the eighteen (18) risk regions identified for the Daly River catchment

Habitat rankings

Habitat rankings were derived simply by applying Jenk's Optimisation algorithm. For wetlands and riparian vegetation, for example, the 4 class natural breaks were applied to their percentage covers. For ranking waterways, drainage density (total drainage length/risk region area) was calculated for each risk region and the natural breaks classification was applied to the drainage density field.

Threat rankings

In some instances further spatial analysis was undertaken on input threat data to enable the application of Jenk's Optimisation for use in the RRM. For land use threats the 4 class natural breaks were applied to percentage cover. Absolute area is another alternative to relative percentage cover, however percentage cover normalises the area of the different risk regions and this issue is explored further in Section 3.5.

Ranking of fire data

The following steps were undertaken in classifying fire risk in each risk region:

- Create a spatial dataset describing the frequency of late dry season fires by extracting post-July fire maps for each year from the national fire affected areas fire history and re-attributing all fires with a value of one (1);
- Overlay and sum the ten (10) years of mapping to describe the number of times each point in the landscape has been affected by late dry season fires;
- Use a spatial layer delineating each catchment to intersect with the resultant late dry season fire frequency layer;
- Undertake a statistical analysis of the natural breaks in the data to create 4 classes: nil, low, medium and high; and
- Calculate the average late dry season fire frequency for each catchment and assign to the catchment the class determined from the natural break statistic.

Ranking of weeds and feral animal (pig) data

The density attributes in both the weed and pig data were recoded as follows:

Absent (or no data) = 0

Occasional or localised = 2

Common and widespread = 4

Abundant and widespread = 6

Due to the fact that these two datasets are based on the Interim Biogeographical Regionalisation of Australia (IBRA) 5 bioregions, there were risk regions with multiple risk rankings. A query was implemented to assign the highest risk ranking to the risk region. In addition, there were multiple recodings in the weed data as each of the weed species has its own density field. These fields were recoded for each weed species and then summed for each risk region. The natural breaks classification was then applied to the summed risk score for total weed species.

Calculating Relative Risk

Risk was calculated as follows (after Walker et al 2001):

Sum of threats in risk region = $\sum$ threats

Sum of potential threat exposure in risk region = ∑ (threat × habitat) only where there is potential exposure

Total risk to ecological assessment endpoint = ∑ (threat × habitat) only where there is potential exposure AND where the threat has the potential to impact the ecological assessment endpoint.

Total risk to ecological assessment endpoint in risk region = ∑ (total risk to ecological assessment endpoint).

An example of the associated risk scores aligned with the conceptual model is shown in Figure 3.17 for one of the Daly River risk regions.

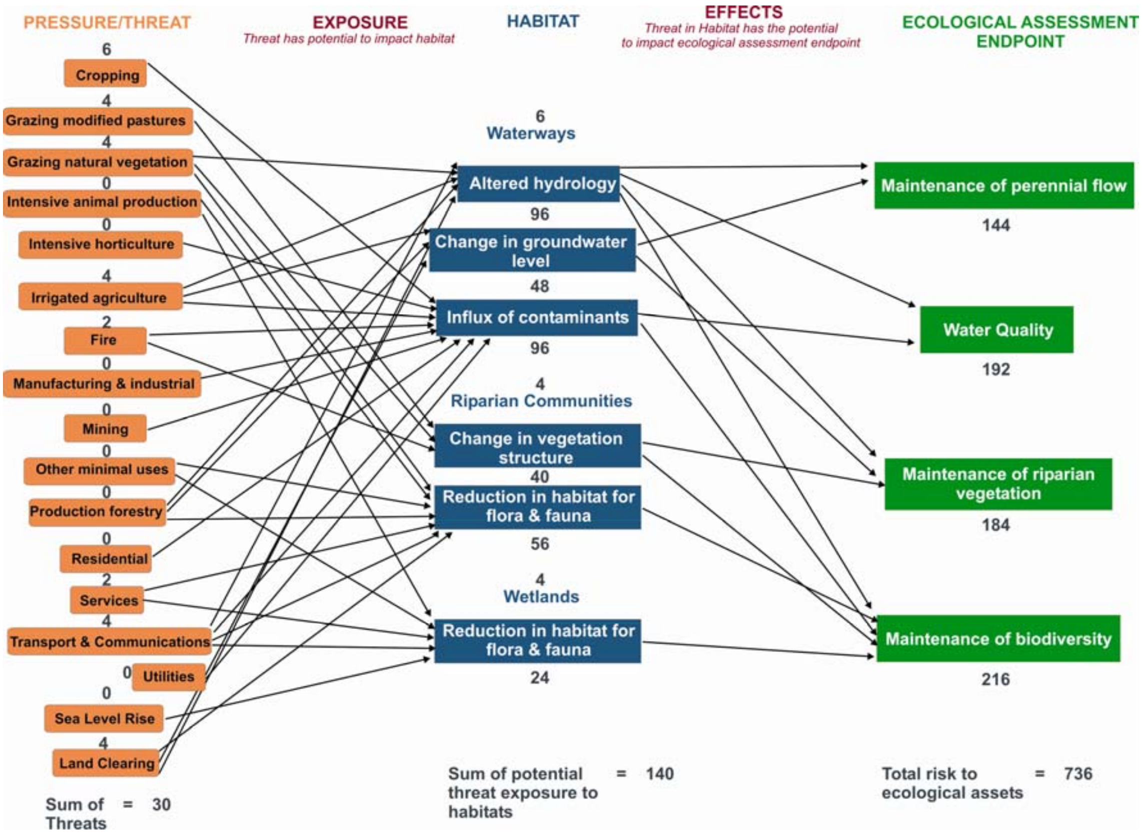


Figure 3.17 Example of risk calculations for Risk Region 1-Daly River, from the Daly River catchment

3.2.5 Risk Characterisation

Risk characteristaion was completed by examining the distribution of habitats and threats as ranked by the RRM, total relative risk and total sum of threats for both scales of application of the RRM, and relative risk to assessment endpoints across the risk regions.

Sensitivity analysis

As stated previously, earlier versions of the RRM outputs not reported here were used due to the iterative nature of model development and application in this project. Four sensitivity tests were undertaken on various components of model input and output.

Firstly, the effect of combining ecological assessment endpoints was tested in earlier versions of the Daly River catchment RRM. In the earlier version of the Daly River RRM, maintenance of aquatic threatened species was included as an assessment endpoint. This endpoint had the same exposure and effects pathways as the water quality assessment endpoint and, therefore, a test was implemented to determine whether or not merging these endpoints would significantly alter the total relative risk rankings of the risk regions.

Secondly, interval analysis (Moore,1979) was used to capture the uncertainty associated with inevitable differences in stakeholder perceptions of interactions between habitats and pressures/threats in the Daly River catchment. Three government and two NGO stakeholders with expert knowledge of the Daly River catchment were asked to use intervals to describe the strength of interaction between pressures/threats and habitats in five selected risk regions. The risk regions chosen represented a varying scale of land use pressure (Daly River, Daly River Estuary, Katherine River, Green Ant Creek and Fish River). The scale of interaction used was:

0 = no effect

0.5 = moderate effect

1 = very strong effect

The minimum an maximum intervals selected by the chosen stakeholders were averaged and then multiplied through the RRM to produce two models, one showing the minimum and the other showing the maximum. The rankings of the risk regions were then compared between the minimum, actual and maximum models to determine whether or not significant changes in rankings had occurred.

Thirdly, the use of a particular spatial dataset to represent a habitat or pressure/threat was tested. Riparian data were tested for the Daly River catchment. The Melaleuca Survey (1993) was compared with the NVIS (2005) data riparian extract in terms of rankings for the risk regions.

Lastly, rankings based on the number of hectares (absolute) compared with percentage of cover (relative) were compared using the sea level rise vulnerability dataset for the Northern Tropical Rivers.

Uncertainty

Uncertainty has been addressed in numerous studies (Clifford et al 1995; Hogsett et al 1997; Landis and Wiegers 1997). Hayes and Landis (2004) used Monte Carlo analysis to describe uncertainty in their rank-based regional risk assessment. In this project, however, uncertainty was simply documented for the conceptual models and spatial data input. Nevertheless, we recommend that in future applications of the RRM uncertainty be dealt with using Monte Carlo simulation in addition to methods such as Interval Maths.

3.3. Risk Characterisation for the Northern Tropical Rivers study area

This section presents the results of the application of the RRM to the Northern Tropical Rivers study area (51 risk regions). Risk characterisation is summarised for habitats, pressures/threats, total relative risk and ecological assessment endpoints.

3.3.1 Habitats

Distribution of habitats (low, medium and high) within the 51 risk regions are shown in Figure 3.18. The percentage cover and number of hectares associated with each category (low, medium and high) are shown in Table 3.8 for riparian vegetation and wetlands, whilst waterways are summarised by drainage density. The maps for riparian vegetation and wetlands shown in Figure 3.18 are based on percentage cover. The rankings change order, however, when maps are generated using number of hectares, as shown in Table 3.8. It is important to note, therefore, that the rankings based on number of hectares in Table 3.8 do not relate to the rankings based on percentage cover per risk region.

The risk regions with the highest drainage density are: McArthur River (NT- Risk Region 32) with a drainage density of 0.92; Fitzmaurice River (NT- Risk Region 12) with a drainage density of 0.89; and Archer River (Qld- Risk Region 46) with a drainage density of 0.79. The risk region with the lowest drainage density is Cape Leveque Coast (WA- Risk Region 1) with a drainage density of 0.13.

The risk regions with the highest percentage cover of riparian vegetation are: Coleman River (Qld- Risk Region 44) – 31%; Moyle River (NT- Risk Region 13) – 23%; and Wildman River (NT- Risk Region 18) – 21%. There are two risk regions, Prince Regent River (Risk Region 5) and King Edward River (Risk Region 6), both located in WA, that are ranked as having 'nil' riparian vegetation. There is riparian vegetation within these largely undisturbed risk regions, however the NVIS data for WA does not account for this.

The risk regions with the highest percentage cover of wetlands are: Adelaide River (NT- Risk Region 16) – 31%; Coleman River (Qld- Risk Region 44) – 29%; and Keep River (NT- Risk Region 10) – 28%. The risk regions with the lowest percentage cover of wetlands are Flinders River (Qld- Risk Region 39) and Drysdale River (WA- Risk Region 7) 1%.

3.3.2 Pressures/Threats

Rankings for pressures/threats (lower, medium and higher) based on percentage cover for each of the 51 risk regions are shown in Figure 3.19. The percentage cover and number of hectares for land uses, frequency for mines and sum of density for weeds are shown in Table 3.9. As stated previously, the rankings for various pressures/threats will change if the maps in Figure 3.19 were to be displayed based on the number of hectares shown in Table 3.9. As stated in Section 3.3.1, the rankings based on number of hectares in Table 3.10 do not relate to the rankings based on percentage cover per risk region.

From the various land uses incorporated in the model, grazing natural vegetation has the highest percentage of cover across the risk regions (see Chapter 2). This is followed by grazing modified pasture. The risk regions with the highest percentage cover of grazing natural vegetation are: Flinders River (Qld- Risk Region 39) – 99%; and Norman and Leichhardt Rivers (Risk Regions 40 and 37 respectively) – 98%. For the majority of risk regions, grazing natural vegetation was the dominant land use. For a number of risk regions (those in the Kakadu region and Arnhem Land in the NT- South Alligator River [Risk Region 19] , East Alligator River [Risk Region 20], Goomadeer River [Risk Region 21], Liverpool River [Risk Region 22), Blyth River [Risk Region 23], Goyder River [Risk Region 24], Buckingham River [Risk Region 26], Koolatong River [Risk Region 27] and Walker River [Risk Region 28]) there is no grazing natural vegetation. However, this is not indicative as to whether this activity does occur in these regions, particularly where there are Aboriginal pastoral enterprises operating at a small scale. Grazing modified pasture is restricted to risk regions within the NT. The risk regions where this land use occurs are: Wildman River (Risk Region 18) – 13%; Adelaide River (Risk Region 16) – 11%; Finniss River (Risk Region 15) – 10%; Mary River (Risk Region 17) – 8% and Daly River (Risk Region 14) – 4.5%.

Irrigated agriculture is a comparatively minor land use across the risk regions, occupying less than 1% of the risk regions where it occurs. Those risk regions with the highest percentage cover of irrigated agriculture are located in the NT and include Adelaide River (Risk Region

16), Wildman River (Risk Region 18) and Finniss River (Risk Region 15). Similarly, cropping is a minor land use and also occupies less than 1% of the risk regions where it occurs. Once again, those risk regions with the highest percentage cover of cropping are within the NT and include Adelaide River (Risk Region 16), Daly River (Risk Region 14) and Finniss River (Risk Region 15).

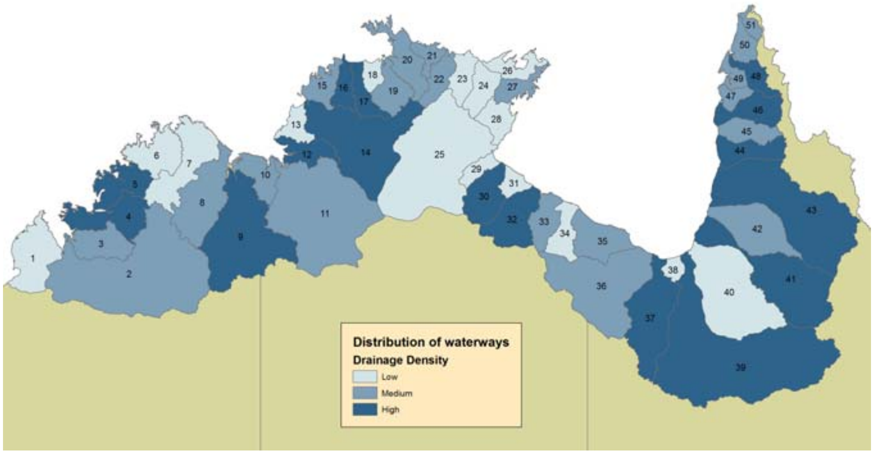
Services and transport and communication land uses are minor land uses also, occupying less than 2% of the risk regions where they occur. The risk regions with the highest percentage cover of services are Jardine River (Qld- Risk Region 51) – 2% and Finniss River (NT- Risk Region 15) – < 1%. The risk region with the highest percentage cover of transport and communications is Finniss River (NT- Risk Region 15) – 1%.

Mining land use (which includes abandoned, exploration, operational and care and maintenance status) occurs in over half of the risk regions. The risk regions with the highest frequencies are located in Queensland and include: Mitchell River (Risk Region 43); Flinders River (Risk Region 39); Gilbert River (Risk Region 41), Norman River (Risk Region 40) and Leichhardt River (Risk Region 37).

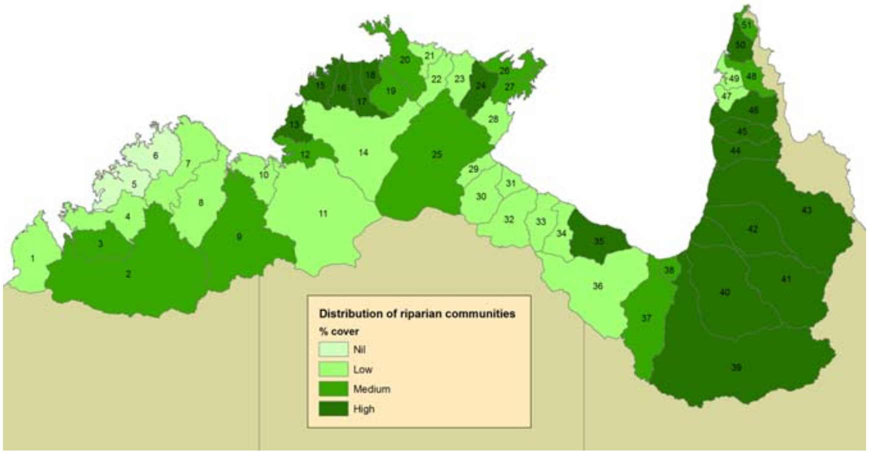
All risk regions were ranked as being vulnerable to sea level rise of up to 1 m. The risk regions with the highest percentage cover of wetlands vulnerable to sea level rise are: Morning Inlet (Qld- Risk Region 38) – 10.5%; Keep River (NT- Risk Region 10) – 2.6%; and Robinson River (NT- Risk Region 33) – 1%. All other risk regions have less than 1% cover of wetlands vulnerable to sea level rise.

The risk region with the highest risk from fire (late dry season fire frequency) is Goomadeer River (NT– Risk Region 21). Other risk regions located in Arnhem Land (NT), Cape York region (Qld) and the coastal catchments of WA have a medium risk from fire. The risk regions with the highest total density of weed species that can affect waterways are: Mitchell River (Risk Region 43); Gilbert River (Risk Region 41); and Flinders River (Risk Region 39). All these regions are located in Queensland. Risk regions where there are no weeds present in this category include: Blyth River (Risk Region 23); Buckingham River (Risk Region 26); Goomadeer River (Risk Region 21); Goyder River (Risk Region 24); Koolatong River (Risk Region 27); and Liverpool River (Risk Region 22) all of which are located in Arnhem Land (NT). This does not imply that the weed species assessed are not present in these risk regions. When the dataset used does not report the occurrence of a weed species in a risk region it most likely reflects a data gap, not an absence.

A



B



C

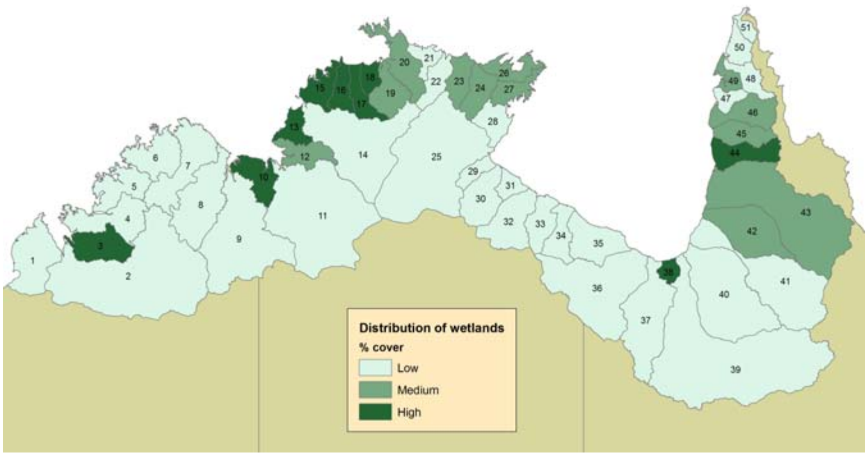


Figure 3.18 Distribution of habitats across the (51) risk regions of the Northern Tropical Rivers. A- waterways ranked by drainage density; B- riparian vegetation ranked by percentage cover; and C- wetlands ranked by percentage cover.

Table 3.8 Rankings of habitats for the Northern Tropical Rivers (waterways, riparian vegetation and wetlands). Waterways were ranked based on drainage density . Percentage cover and hectare rankings are displayed for riparian vegetation and wetlands.

Drainage Density			
Waterways			
Low	0.13 – 0.48		
Medium	0.49 – 0.63		
High	0.64 – 0.92		
Percentage Cover		**Number of Hectares**	
Riparian vegetation			
Nil	0	Nil	0
Low	1.11 – 6.36	Low	9,548 – 222,243
Medium	6.37 – 13.51	Medium	222,244 – 712,138
High	13.52 – 31.22	High	712,139 – 1,915,059
Wetlands			
Low	1.12 – 8.34	Low	15,476 – 158,572
Medium	8.35 – 15.52	Medium	158,573 – 443,307
High	15.53 – 30.63	High	443,308 – 824,595

3.3.3 Total Relative Risk

The total relative risk (lower, medium and higher) for the 51 risk regions in the Northern Tropical Rivers Study area is shown in Figure 3.20. The risk regions at higher risk from the specified threats are: Adelaide River (NT– Risk Region 16); Finniss River (NT– Risk Region 15); Mitchell River (Qld– Risk Region 43); Leichhardt River (Qld– Risk Region 37); Flinders River (Qld– Risk Region 39); Gilbert River (Qld– Risk Region 41); Daly River (NT– Risk Region 14); and Mary River (NT– Risk Region 17). There are no risk regions ranked as higher within Western Australia. This does not necessarily imply that there are no risk regions at higher risk located within WA. The spatial data that has been sourced from WA is of a coarser scale compared with the datasets for the NT and Qld and, therefore, some threats or assets may not be detected.

The total relative risk scores for the 51 risk regions are shown in Figure 3.21. The risk regions with the highest total risk scores are Adelaide River (Risk Region 16) – 1344, followed by Finniss River (Risk Region 15) – 1240, Mitchell River (Risk Region 43) – 1220 and Leichhardt River (Risk Region 37) – 1100. Conversely the risk regions with the lowest risk scores are Blyth River (Risk Region 23) – 72, Goomadeer River (Risk Region 21) – 76, and Walker River (Risk Region 28) – 76.

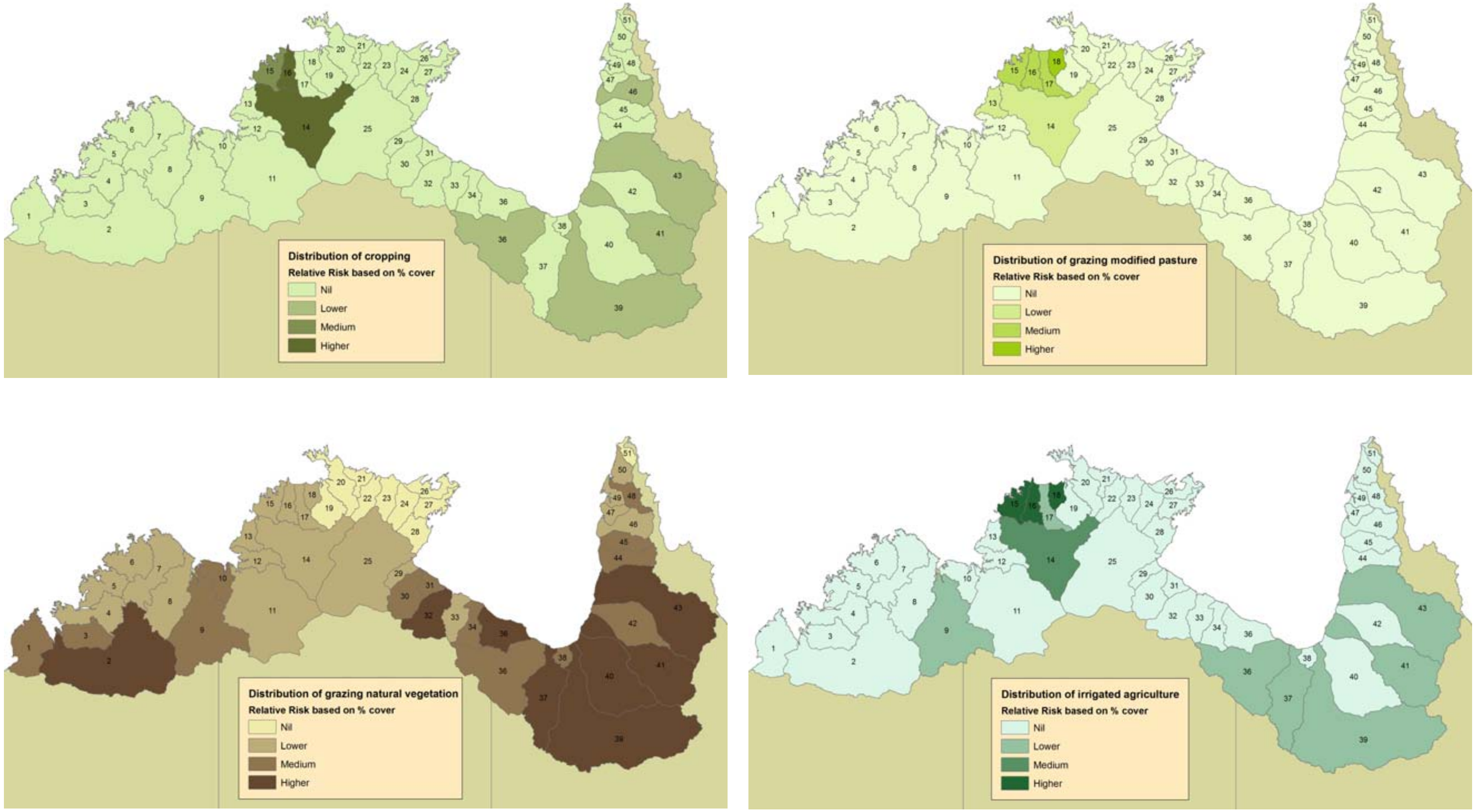


Figure 3.19 Rankings for pressures/threats based on percentage cover for each of the 51 risk regions across the Northern Tropical Rivers study area

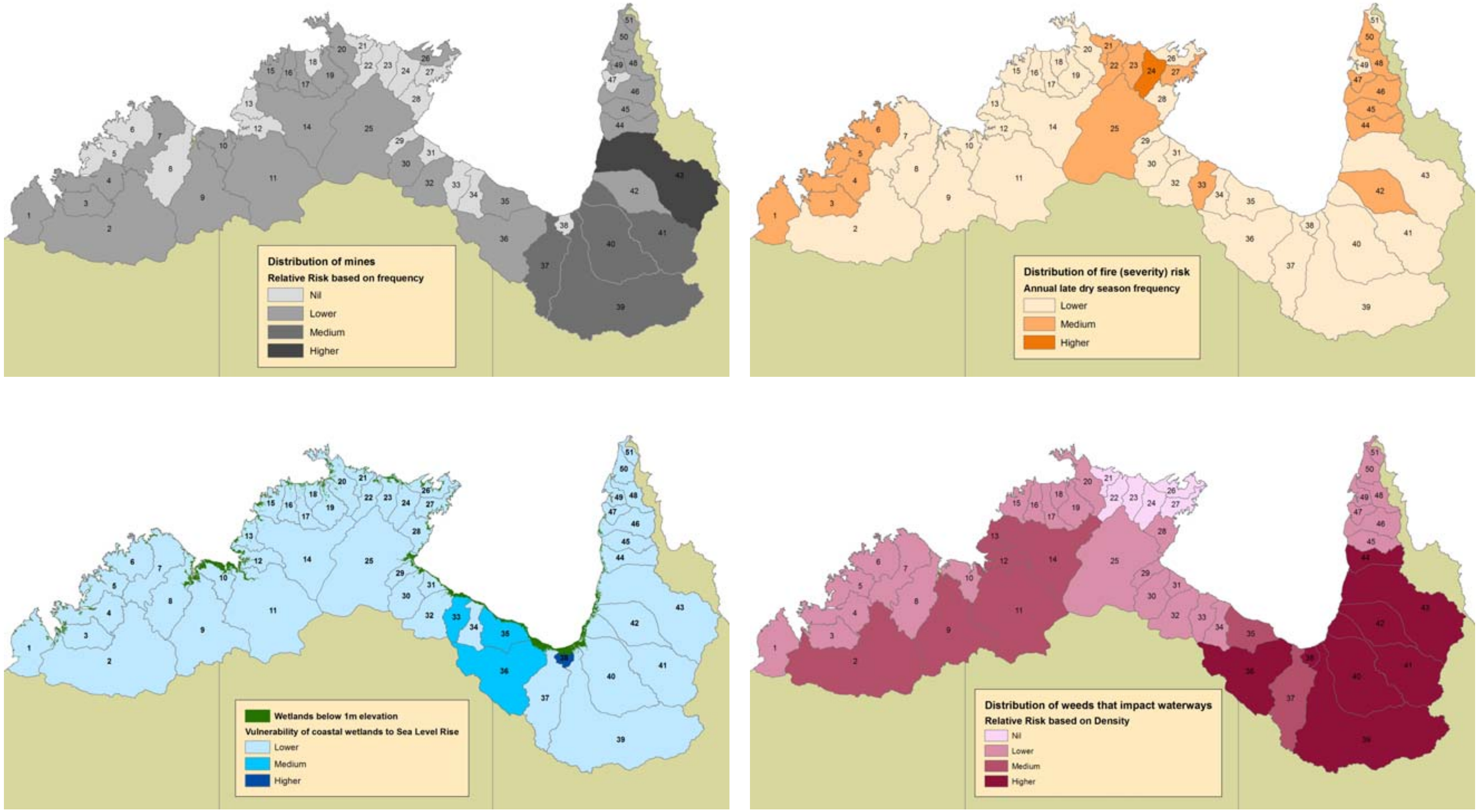


Figure 3.19 (continued) Rankings for pressures/threats based on percentage cover for each of the 51 risk regions across the Northern Tropical Rivers study area

Table 3.9 Rankings of pressures/threats for the Northern Tropical Rivers based on percentage cover and number of hectares (unless stated otherwise)

Frequency			
Mines			
Nil	0		
Lower	1 - 181		
Medium	182 - 1188		
Higher	1189 - 3176		
Percentage Cover		**Number of Hectares**	
Cropping			
Nil	0	Nil	0
Lower	0.000001 - 0.018331	Lower	107 – 2,177
Medium	0.018332 - 0.229420	Medium	2,178 – 4,293
Higher	0.229421 - 0.573273	Higher	4,294- 27,893
Grazing modified pasture			
Nil	0	Nil	0
Lower	0.000001 - 4.576409	Lower	<1 - 69
Medium	4.576410 - 11.129051	Medium	70 – 96,453
Higher	11.129052 - 13.493883	Higher	96,454 – 244,339
Grazing natural vegetation			
Nil	0	Nil	0
Lower	0.000001 - 60.402634	Lower	29 – 2,068,394
Medium	60.402635 - 85.596155	Medium	2,068,395 - 4,944,725
Higher	85.596156 - 99.142853	Higher	4,944,726 – 10,908,658
Irrigated agriculture			
Nil	0	Nil	0
Lower	0.000001 - 0.059799	Lower	<1- 2,491
Medium	0.059800 - 0.232763	Medium	2,492 – 7,251
Higher	0.232764 - 0.859589	Higher	7,252 – 14,682
Services			
Nil	0	Nil	0
Lower	0.000001 - 0.442398	Lower	<1 – 1,714
Medium	0.442399 - 0.942768	Medium	1,715 – 8,946
Higher	0.942769 - 1.949708	Higher	8,947 – 23,620
Transport & Communications			
Nil	0	Nil	0
Lower	0.000001 - 0.217954	Lower	<1 – 3,390
Medium	0.217955 - 0.493977	Medium	3,391 – 12,155
Higher	0.493978 - 1.280876	Higher	12,156 – 21,725
Sea level rise			
Lower	0.000588 - 0.680611	Lower	2 – 5,644
Medium	0.680612 - 2.585678	Medium	5,645 – 18,301
Higher	2.585679 - 10.573437	Higher	18,302 – 44,393

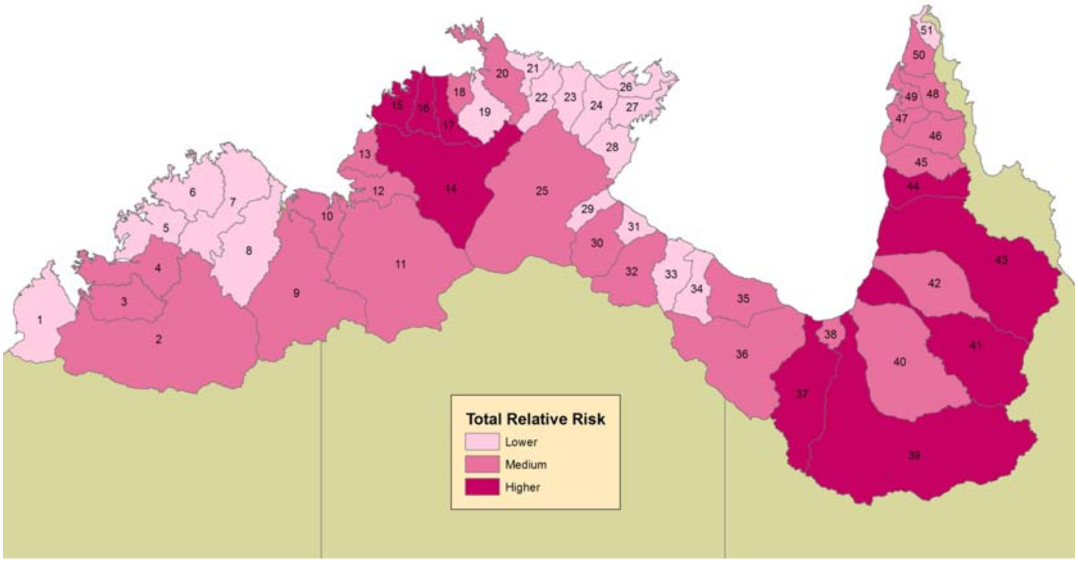


Figure 3.20 Total relative risk shown as higher, medium or lower for the 51 risk regions within the Northern Tropical Rivers study area

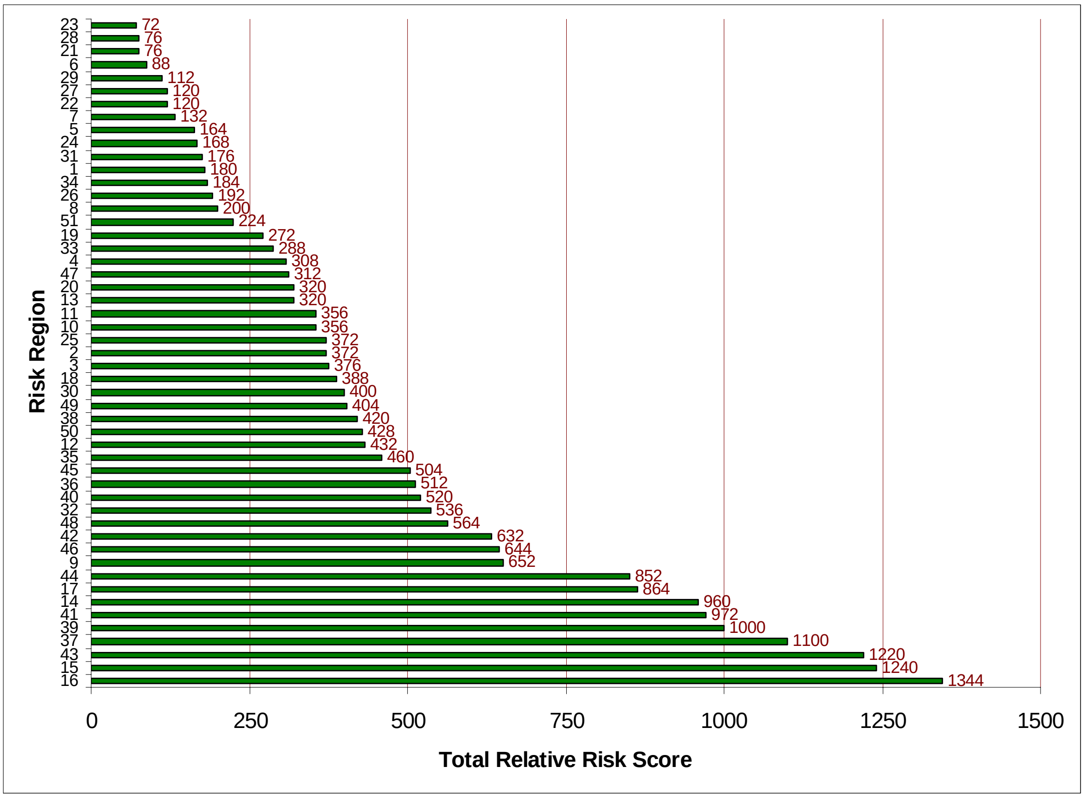


Figure 3.21 Total relative risk scores for the 51 risk regions within the Northern Tropical Rivers study area

3.3.4 Total sum of threats

Figure 3.22 summarises the sum of threats for each threat included within the RRM. This analysis shows that grazing natural vegetation (192) is the threat with the largest relative score followed by feral pigs (174) and fire (142). The threats with the lowest relative score are grazing modified pasture (12) followed by waste treatment and disposal (14) and forestry (16). The summing of threats does not take into account that the interaction of threats may be multiplicative in nature.

3.3.5 Ecological Assessment Endpoints

The relative risk scores for the ecological assessment endpoints across the 51 risk regions in the Northern Tropical Rivers Study area are shown in Table 3.10. The ecological assessment endpoint with the highest total risk is maintenance of biodiversity (11 260). Conversely, the ecological assessment endpoint with the lowest total risk is maintenance of flow regime (2324). Figure 3.23 shows the relative risk rankings for the ecological assessment endpoints across the 51 risk regions.

The risk regions with the highest total risk for maintenance of flow regime are: Leichhardt River (Risk Region 37) - 188; Mitchell River (Risk Region 43) -156; Daly and Adelaide Rivers (Risk Regions 14 and 16 respectively) – 144; and Ord River (Risk Region 9) - 96.The Ord River is not ranked first despite there being comparatively significant irrigation activities in the region (refer to Chapter 2) as the percentage cover of the various land use types that impact on flow regime are comparatively lower than those from regions ranked higher. In addition, dams which affect flow regime were not included in the model and this is discussed further in Chapter 5 (Section 5.5). There are a number of catchments located within Arnhem Land allocated 'nil' risk for maintenance of flow regime (Blyth [Risk Region 23], Goomadeer [Risk Region 21], Goyder [Risk Region 24], Koolatong [Risk Region 27] and Liverpool Rivers [Risk Region 23]). These 'nil' rankings are due to zero scores for *altered hydrology* and *change in groundwater levels* impacts to waterway habitats. The zero score for altered hydrology is derived from 'nil' rankings for weeds and land uses such as grazing natural vegetation (although these pressures/threats may be present in these risk regions). The zero score for change in groundwater level is derived from 'nil' rankings for irrigated agriculture and forestry land uses.

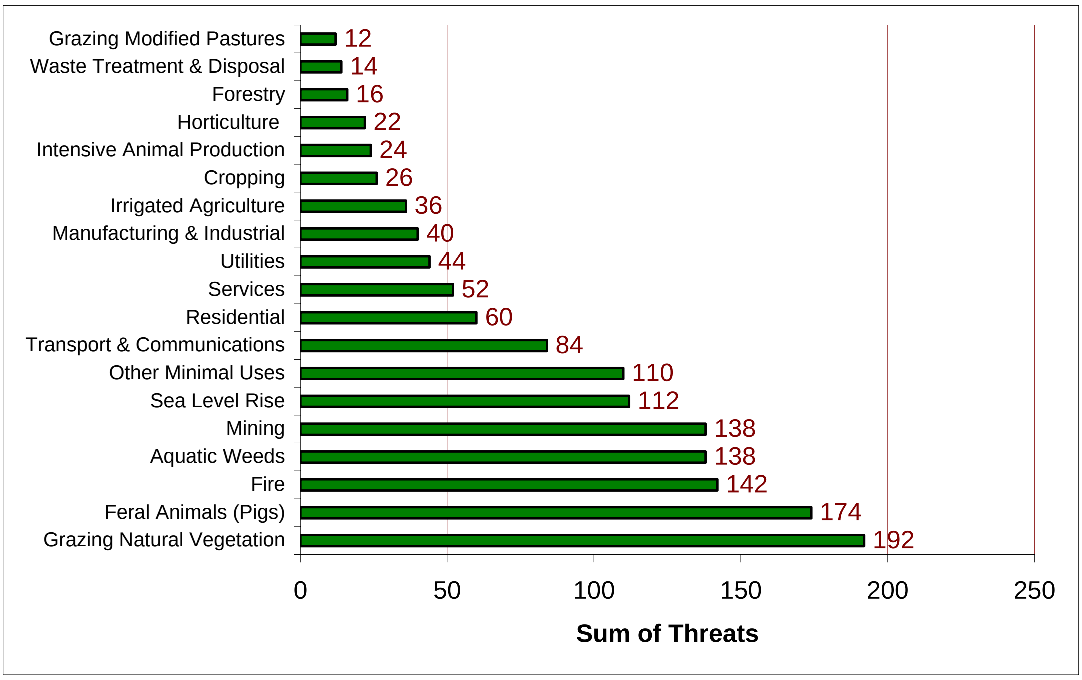


Figure 3.22 Sum of threats for each threat included in the RRM for the Northern Tropical Rivers study area

The risk regions with the highest total risk to water quality are: Adelaide River (Risk Region 16) - 336; Finniss River (Risk Region 15) - 272 and Daly River (Risk Region 14) - 264. It was expected that the Ord River (Risk Region 9), which ranked seventh, would have ranked higher. However, once again due to a comparatively lower percentage of land uses impacting on water quality, the region did not rank higher. Conversely, the risk regions with the lowest total risk for water quality are: Blyth River (Risk Region 23) - 8; Goyder, Walker and Towns Rivers (Risk Regions 24, 28 and 29 respectively) - 12. The high total risk scores for the Adelaide (Risk Region 16) and Finniss Rivers (Risk Region 15) are associated with high scores for altered hydrology and influx of contaminants impacts to waterway habitats. These scores are due to high rankings for irrigated agriculture, horticulture, cropping and residential land uses. The lower risk scores for Blyth (Risk Region 23), Goyder, Walker and Towns Rivers (Risk Regions 24, 28 and 29 respectively) are because there were many zero risk rankings for the pressures/threats linked to impacts on waterway habitats. Fire was the main input into the risk scores for these risk regions.

The risk regions with the highest total risk for maintenance of riparian vegetation are: Mitchell River (Risk Region 43) - 264; Leichhardt River (Risk Region 37) - 232; Adelaide, Gilbert and Flinders Rivers (Risk Regions 16, 41 and 39 respectively) - 216. The risk regions with the lowest total risk for maintenance of riparian vegetation are: King Edward River (Risk Region 6) - 12; Blyth, Walker and Goomadeer Rivers (Risk Regions 23, 28 and 21 respectively) -16. The high total risk scores for the Mitchell (Risk Region 43), Leichhardt, Adelaide, Gilbert and Flinders Rivers (Risk Regions 16, 41 and 39 respectively) are due to high rankings for waterway and riparian community habitats combined with high rankings for various pressures/threats. The high scores for altered hydrology impacts to waterways for the Mitchell (Risk Region 43) and Leichhardt Rivers (Risk Region 37) are due to high rankings for grazing natural vegetation, irrigated agriculture, forestry and weeds pressures/threats. Similarly, the high scores for change in vegetation structure impacts to riparian communities are attributed to high rankings for grazing natural vegetation, pigs and weeds pressures/threats. The pressures/threats contributing to the high score for altered hydrology impacts to waterways of the Adelaide River (Risk Region 16) are irrigated agriculture and transport and communications, whilst grazing natural vegetation and weeds both had high rankings and contributed to the change in vegetation structure impacts in riparian communities. In the Gilbert and Flinders Rivers risk regions (Risk Regions 41 and 39, respectively), high scores for altered hydrology impacts to waterways and change in vegetation structure in riparian communities are associated with high rankings for grazing natural vegetation, pigs and weeds pressures/threats. In contrast, the risk regions with lower total risk for maintenance of riparian vegetation have habitats with low rankings combined with 'nil' ranking for a number of pressures/ threats (King Edward River [Risk Region 6] has a 'nil' ranking for riparian habitat).

For assessments of maintenance of biodiversity, the risk regions with the highest total risk are: Finniss River (Risk Region 15) - 668; Adelaide River (Risk Region 16) - 648 and Mitchell River (Risk Region 43) - 548. The high risk scores are due in general to the combination of high rankings for habitats and pressures/threats, and the interaction of these with impacts. The risk regions with the lowest total risk are: Liverpool River (Risk Region 22) - 36; King Edward (Risk Region 6), Walker and Goomadeer Rivers (Risk Regions 28 and 21 respectively) -44. The lower risk scores are due to the combination of low risk rankings for habitats and pressures/threats.

Table 3.10 Risk scores for ecological assessment endpoints (maintenance of flow regime, water quality, maintenance of riparian vegetation and maintenance of biodiversity) output from the RRM for the 51 risk regions

	Assessment Endpoints				
Risk Region	**Maintenance of flow regime**	**Water quality**	**Maintenance of riparian vegetation**	**Maintenance of biodiversity**	**Total Risk by Region**
1	16	28	40	96	180
2	40	56	96	180	372
3	32	56	88	200	376
4	36	72	60	140	308
5	24	48	24	68	164
6	12	20	12	44	88
7	12	20	32	68	132
8	24	32	48	96	200
9	96	132	160	264	652
10	40	64	68	184	356
11	40	80	68	168	356
12	48	72	96	216	432
13	12	16	96	196	320
14	144	264	180	372	960
15	120	272	180	668	1240
16	144	336	216	648	1344
17	84	156	192	432	864
18	36	44	96	212	388
19	16	48	48	160	272
20	16	72	48	184	320
21	0	16	16	44	76
22	0	24	60	36	120
23	0	8	16	48	72
24	0	12	60	96	168
25	20	52	76	224	372
26	4	32	28	128	192
27	0	16	32	72	120
28	4	12	16	44	76
29	8	12	24	68	112
30	60	96	84	160	400
31	20	28	44	84	176
32	72	144	96	224	536
33	32	64	56	136	288
34	20	28	44	92	184
35	40	56	136	228	460
36	72	120	108	212	512
37	168	252	232	448	1100

Table 3.10 (continued)

	Assessment Endpoints				
Risk Region	**Maintenance of flow regime**	**Water quality**	**Maintenance of riparian vegetation**	**Maintenance of biodiversity**	**Total Risk by Region**
38	28	40	100	252	420
39	108	216	216	460	1000
40	28	56	136	300	520
41	108	216	216	432	972
42	56	88	176	312	632
43	156	252	264	548	1220
44	84	144	204	420	852
45	40	72	136	256	504
46	48	132	132	332	644
47	32	64	60	156	312
48	60	120	124	260	564
49	32	96	56	220	404
50	24	72	96	236	428
51	8	40	40	136	224
Total Risk for Assessment Endpoint	2324	4468	4932	11260	22984

Table Key

	Nil	Lower	Medium	Higher
Flow Regime				
Water Quality				
Riparian Vegetation				
Biodiversity				

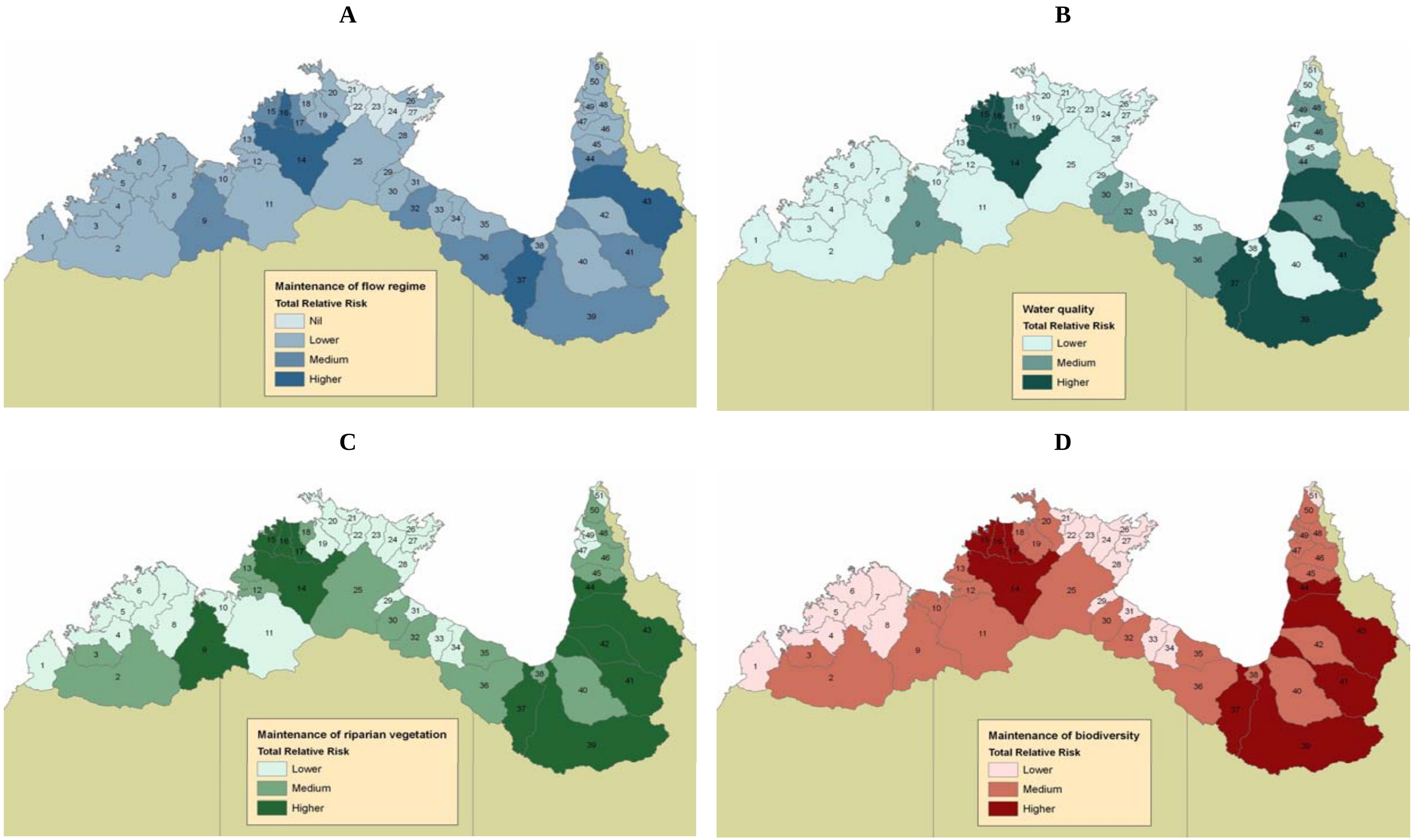


Figure 3.23 Relative risk to ecological assessment endpoints across the (51) risk regions of the Northern Tropical Rivers. A- maintenance of flow regime; B- water quality; C- maintenance of riparian vegetation; and D- maintenance of biodiversity.

3.4. Risk characterisation for the Daly River catchment

This section presents the results of the application of the RRM to the Daly River catchment (18 risk regions). As in the previous section, risk characterisation is summarised for habitats, pressures/threats, total relative risk and ecological assessment endpoints.

3.4.1 Habitats

Distribution of habitats (low, medium and high) within the 18 risk regions are shown by Figure 3.24. The percentage cover and number of hectares associated with each category (low, medium and high) are shown in Table 3.11 for riparian vegetation and wetlands, whilst waterways are summarised by drainage density. The maps for riparian vegetation and wetlands shown in Figure 3.24 are based on percentage cover. The rankings will change if the maps were displayed using number of hectares as shown in Table 3.11. It is important to note that the rankings based on number of hectares in Table 3.11 do not relate to the rankings based on percentage cover per risk region.

The risk regions with the highest drainage density are: Fish River (Risk Region 15) – 1.36; Bradshaw Creek (Risk Region 13) – 1.31; and Chilling Creek (Risk Region 16) – 1.24. The risk region with the lowest drainage density is King and Dry Rivers (Risk Region 10) with a drainage density of 0.25.

The risk regions with the highest percentage cover of riparian vegetation are: Daly River Estuary (Risk Region 18) – 30%; King and Dry Rivers (Risk Region 10) 8%; and Green Ant Creek (Risk Region 3) – 6%. The risk regions with the lowest percentage cover of riparian vegetation are: Fish River (Risk Region 15) – 0.45% and Limestone Creek (Risk Region 11) – 0.5%.

The risk regions with the highest percentage cover of wetlands are: Daly River Estuary (Risk Region 18) - 30%; Green Ant Creek (Risk Region 3) – 6%; and Daly River (Risk Region 1) – 3%. The risk region with the lowest percentage cover of wetlands is Upper Katherine River (Risk Region 18) – 0.28%.

Table 3.11 Rankings of habitats for the Daly River catchment (waterways, riparian vegetation and wetlands). Waterways were ranked based on drainage density. Percentage cover and hectare rankings are displayed for riparian vegetation and wetlands.

Drainage Density			
Waterways			
Low	0.25 – 0.4		
Medium	0.41 – 0.80		
High	0.81 – 1.36		
Percentage Cover		**Number of Hectares**	
Riparian vegetation			
Low	0.45 – 2.13	Low	620 – 5,885
Medium	2.14 – 7.7	Medium	5,886 – 21,183
High	7.71 – 29.76	High	21,184 – 147,733
Wetlands			
Low	0.29 – 1.74	Low	95 – 3,028
Medium	1.75 – 5.7	Medium	3,029 – 11,606
High	5.71 – 30.05	High	11,607 – 149,160

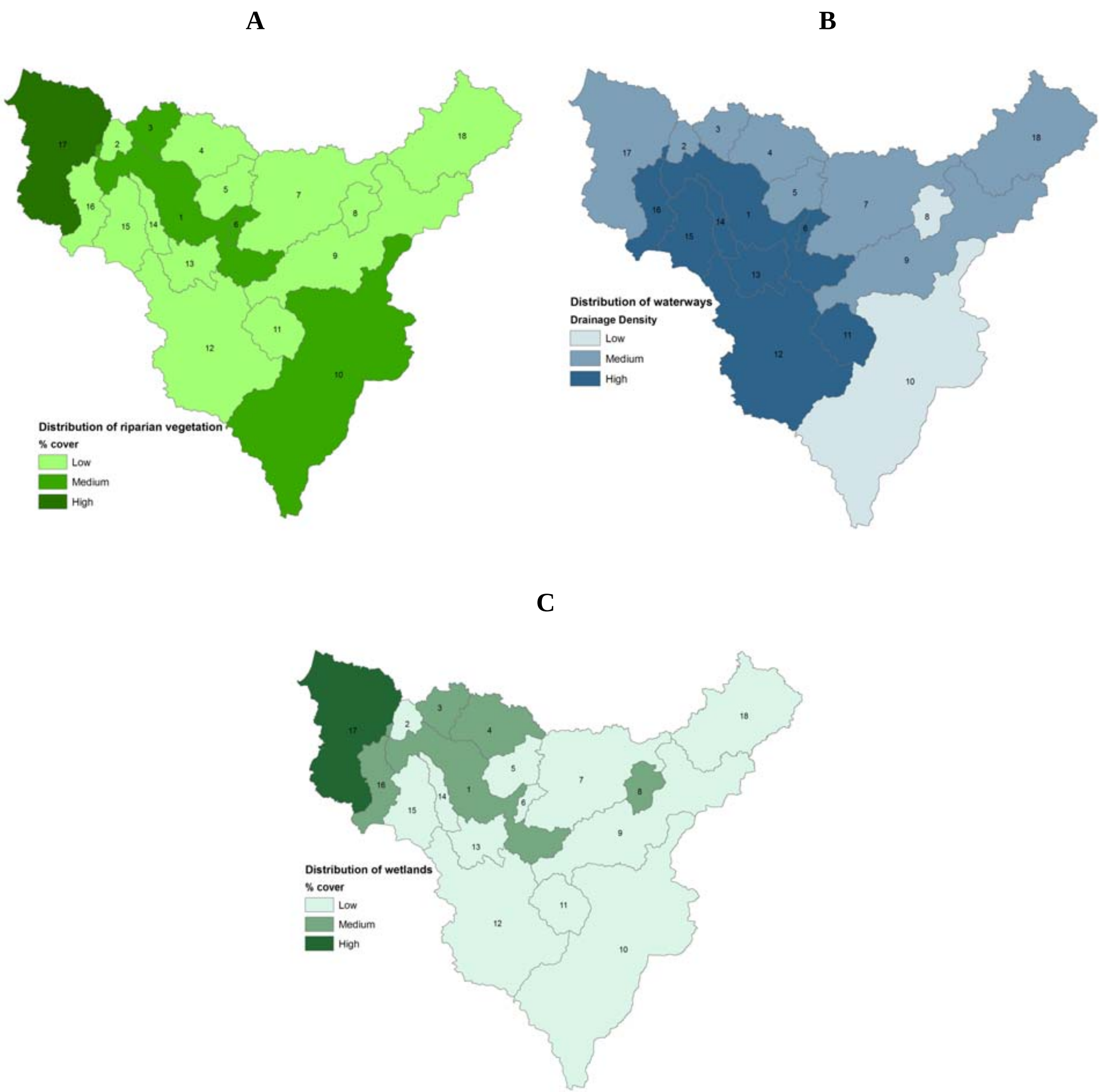


Figure 3.24 Distribution of habitats across the (18) risk regions of the Daly River catchment. A – riparian vegetation ranked by percentage cover; B – waterways ranked by drainage density and C – wetlands ranked by percentage cover.

3.4.2 Pressures/Threats

Rankings for pressures/threats (lower, medium and higher) based on percentage cover for each of the 18 risk regions are shown in Figure 3.25. The percentage cover and number of hectares for land uses, frequency for mines and land clearing are shown in Table 3.12. As stated previously the rankings for various pressures/threats will change if the maps in Figure 3.25 used number of hectares as shown in Table 3.12. As stated in Section 3.4.1, the rankings based on number of hectares in Table 3.12 do not relate to the rankings based on percentage cover per risk region.

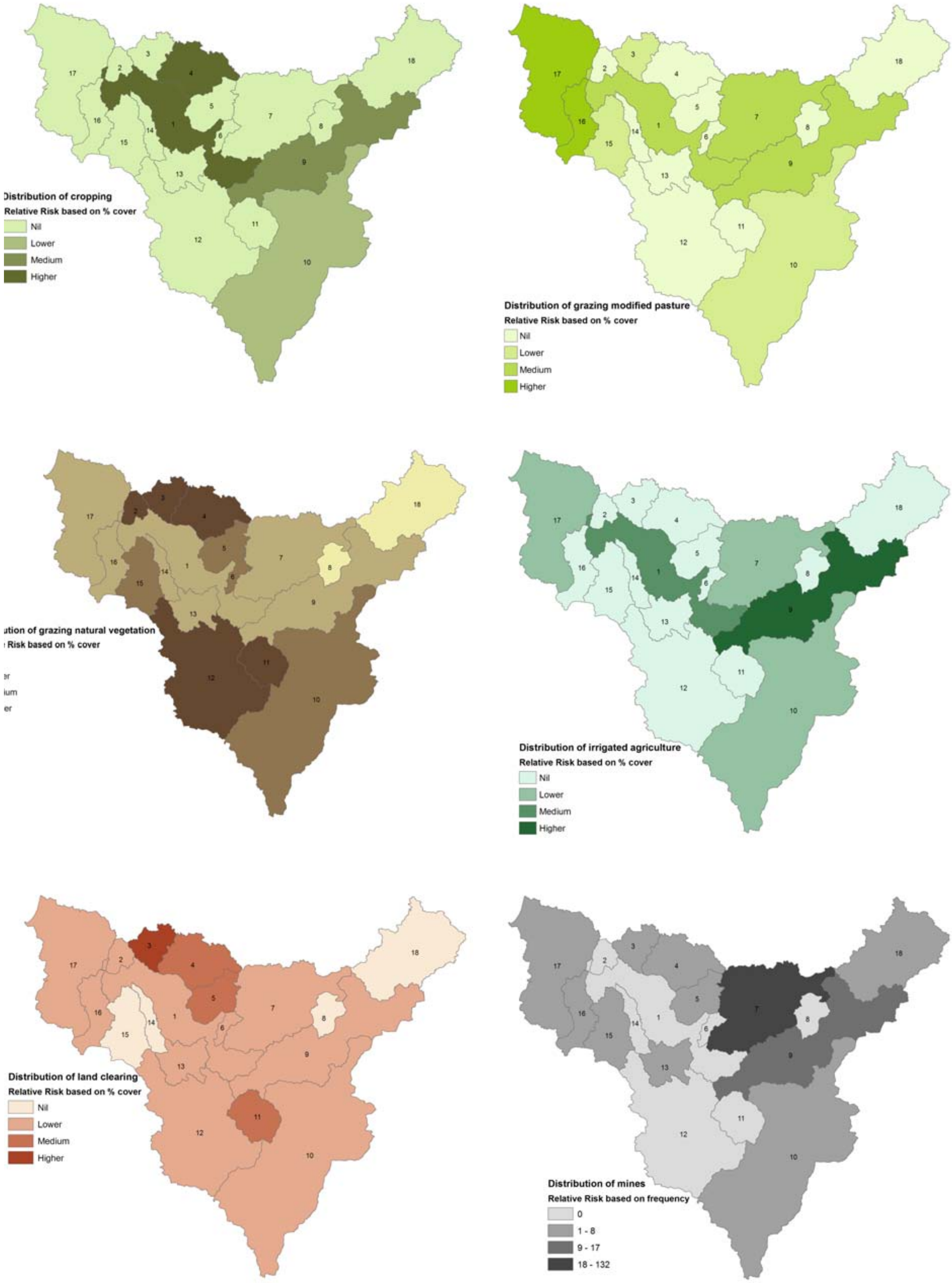


Figure 3.25 Distribution of pressures/threats across the (18) risk regions of the Daly River catchment (continued over-page)

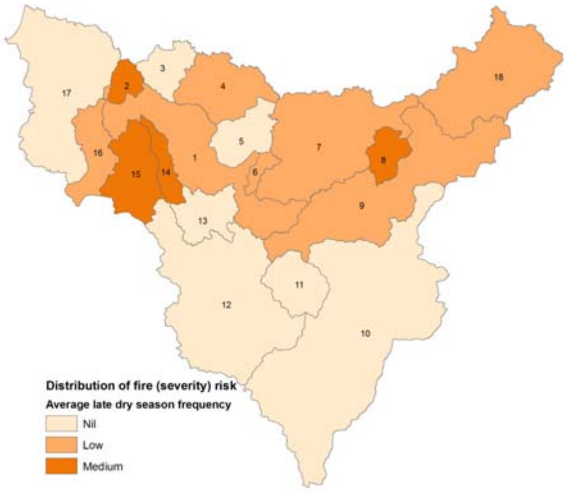


Figure 3.25 (continued) Distribution of pressures/threats across the (18) risk regions of the Daly River catchment

As with the application of the RRM to the Northern Tropical Rivers study area (Section 3.3.1) that incorporated various land uses, grazing natural vegetation has the highest percentage of cover across the risk regions. This is followed by land clearing. The risk regions with the highest percentage cover of grazing natural vegetation are: Limestone Creek (Risk Region 11) – 99%; and Green Ant and Hayward Creeks (Risk Regions 3 and 2 respectively) – 98%. For the Upper Katherine River (Risk Region 18) and Seventeen Mile Creek (Risk Region 8) there is no grazing natural vegetation. The risk regions with the highest percentage of land clearing are: Green Ant Creek (Risk Region 3) – 60%; Limestone Creek (Risk Region 11) – 16%; and Douglas River (Risk Region 4) – 15%. Conversely, there is no land clearing recorded in the dataset for Upper Katherine River (Risk Region 18), Bamboo (Moon Boon) Creek (Risk Region 14), Fish River (Risk Region 15) and Seventeen Mile Creek (Risk Region 8).

Grazing modified pasture is not a widespread land use throughout the Daly River catchment. There is no grazing modified land use for 10 out of 18 risk regions. The risk regions where this land use occurs are: Chilling Creek (Risk Region 16) – 47%; Daly River Estuary (Risk Region 17) – 26%; Daly River (Risk Region 1) – 5%; Katherine River, Fergusson River, Fish River, Green Ant Creek and King and Dry Rivers (Risk Regions 9, 7, 15, 3 and 10) – <5%.

Irrigated agriculture is a comparatively minor land use across the risk regions, occupying five out of the 18 risk regions, and covering less than 2% of the risk regions where it does occur The risk regions with the highest percentage cover of irrigated agriculture is Katherine River (Risk Region 9) – 2%. For the Daly River (Risk Region 1), Daly River Estuary (Risk Region 17), King and Dry Rivers (Risk Region 10) and Fergusson River (Risk Region 7), irrigated agriculture occupies <1% of the risk region. Similarly, cropping is not widespread with this land use occurring in only four of the 18 risk regions: Douglas River (Risk Region 4) – 5%; Daly River (Risk Region 1) – 4%; and Katherine and King and Dry Rivers (Risk Regions 9 and 10 respectively) – <0.1%.

Services and transport and communication land uses are minor land uses also occupying less than 3% and 1% of the risk regions they occur in respectively. The risk regions with the highest percentage cover of services are Katherine River (Risk Region 9) – 3% and Douglas River (Risk Region 4) – 1%. The risk region with the highest percentage cover of transport and communications is Fergusson River (Risk Region 7) – 0.67%.

Mining land use (which includes abandoned, mineral occurrence and prospect status) occurs in 11 out of the 18 risk regions. The risk regions with the highest frequencies of mines include: Fergusson River (Risk Region 7) – 132; Katherine River (Risk Region 9) – 17; and Douglas River (Risk Region 4) – 8.

Table 3.12 Rankings of pressures/threats for the Daly River catchment based on percentage cover and number of hectares (unless stated otherwise)

Frequency			
Mines			
Nil	0		
Lower	1 – 8		
Medium	9 - 17		
Higher	18 - 132		
Percentage Cover		**Number of Hectares**	
Cropping			
Nil	0	Nil	0
Lower	0.000001 - 0.020535	Lower	1 - 434
Medium	0.020536 - 0.098959	Medium	435 – 10,087
Higher	0.098960 - 5.116986	Higher	10,088 – 17,034
Grazing modified pasture			
Nil	0	Nil	0
Lower	0.000001 - 0.250200	Lower	15 - 870
Medium	0.250201 - 5.111996	Medium	871 – 9,833
Higher	5.111997 - 46.998111	Higher	9,834 – 70,623
Grazing natural vegetation			
Nil	0	Nil	0
Lower	0.000001 - 52.992328	Lower	1 – 174,376
Medium	52.992329 - 79.243311	Medium	174,377 – 303,845
Higher	79.243312 - 99.474545	Higher	303,846 – 796,622
Irrigated agriculture			
Nil	0	Nil	0
Lower	0.000001 - 0.063294	Lower	103 -393
Medium	0.063295 - 0.159814	Medium	394 - 946
Higher	0.159815 - 1.922133	Higher	947 – 10,587
Land clearing			
Nil	0	Nil	0
Lower	0.000001 - 7.965772	Lower	0.1 - 14,054
Medium	7.965773 - 16.457587	Medium	14,055 - 32,171
Higher	16.457588 - 58.908966	Higher	32,172 - 54,042

The Daly River Estuary (Risk Region 17) is the only risk region ranked as being vulnerable to sea level rise of up to 1 m.

The risk regions with the highest risk from fire (frequency of late dry season fires) are: Seventeen Mile Creek (Risk Region 8); Fish River (Risk Region 15); Bamboo (Moon Boon) Creek (Risk Region 14); and Hayward Creek (Risk Region 2). It should be noted that these are ranked as medium risk, not higher risk. Risk regions with 'nil' risk from fire include:

Daly River Estuary (Risk Region 17); Green Ant Creek (Risk Region 3); Stray Creek (Risk Region 5); King and Dry Rivers (Risk Region 10); Bradshaw Creek (Risk Region 13); Flora River (Risk Region 12); and Limestone Creek (Risk Region 11).

3.4.3 Total Relative Risk

The overall risk classification (lower, medium, higher) calculated using Jenk's Optimisation for the 18 risk regions in the Daly River catchment area is shown in Figure 3.26. The risk model indicates the risk regions at higher risk from the specified pressures/threats are: Daly River (Risk Region 1); Green Ant Creek (Risk Region 3); Douglas River (Risk Region 4); Katherine River (Risk Region 9); King and Dry Rivers (Risk Region 10); Limestone Creek (Risk Region 11); and Daly River Estuary (Risk Region 17).

The total relative risk scores for the 18 risk regions are shown in Figure 3.27. The risk regions with the highest total risk scores are Daly River (Risk Region 1) - 706 followed by Douglas and Katherine Rivers (Risk Regions 4 and 9 respectively) - 580, Green Ant Creek (Risk Region 3) -572, King and Dry Rivers (Risk Region 10) - 564, Limestone Creek (Risk Region 11) - 548 and Daly River Estuary (Risk Region 17) - 512. Conversely the risk regions with the lowest risk scores are Upper Katherine River (Risk Region 18) - 24, Seventeen Mile Creek (Risk Region 8) - 40, and Hayward Creek (Risk Region 2) - 144.

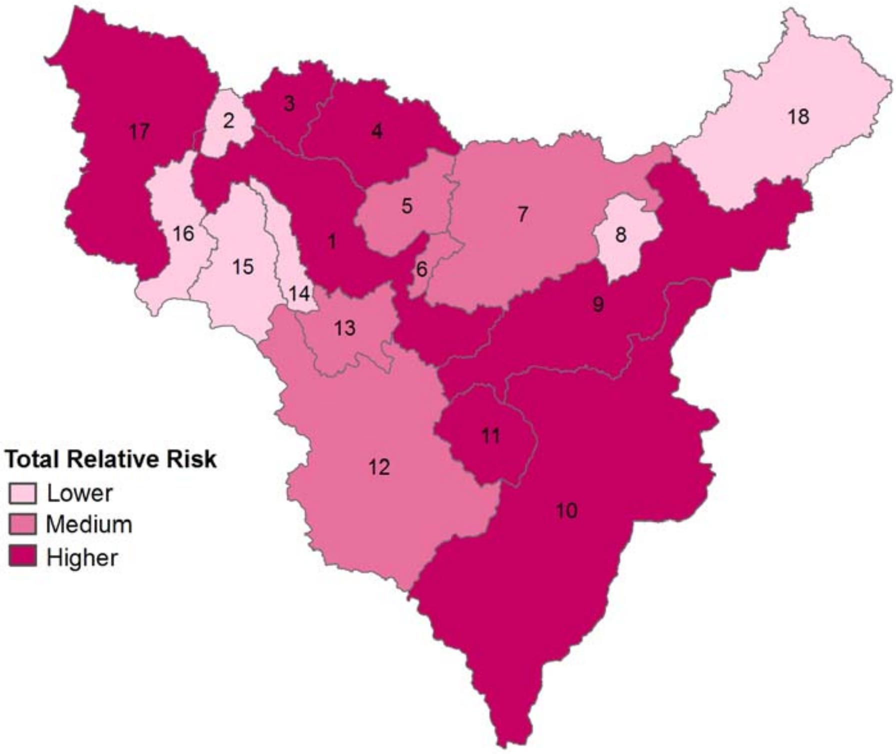


Figure 3.26 Relative risk classification for the 18 Risk Regions identified for the Daly River catchment

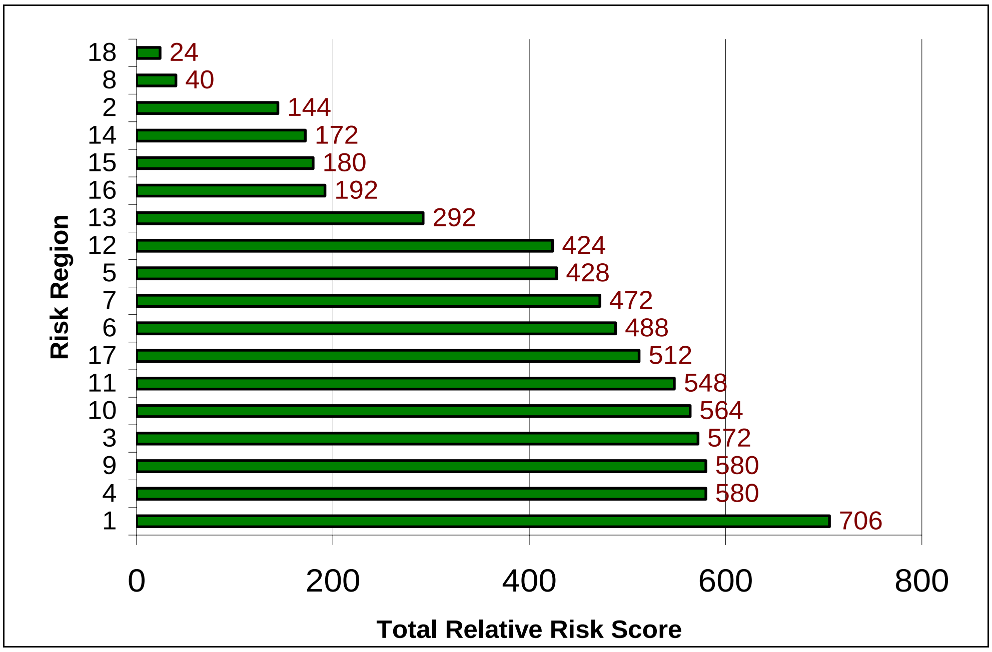


Figure 3.27 Total Relative Risk scores for each of the 18 risk regions within the Daly River catchment

3.4.4 Total sum of threats

Figure 3.28 summarises the sum of threats for each threat included within the RRM. The analysis shows that grazing natural vegetation (60) is the threat with the largest relative score, followed by transport and communications (48) and then land clearing (44). The threats with the lowest relative score are production forestry, manufacturing and industrial, intensive horticulture and intensive animal production (2). As mentioned previously, the summing of threats does not account for the interaction of threats, which may be multiplicative in nature.

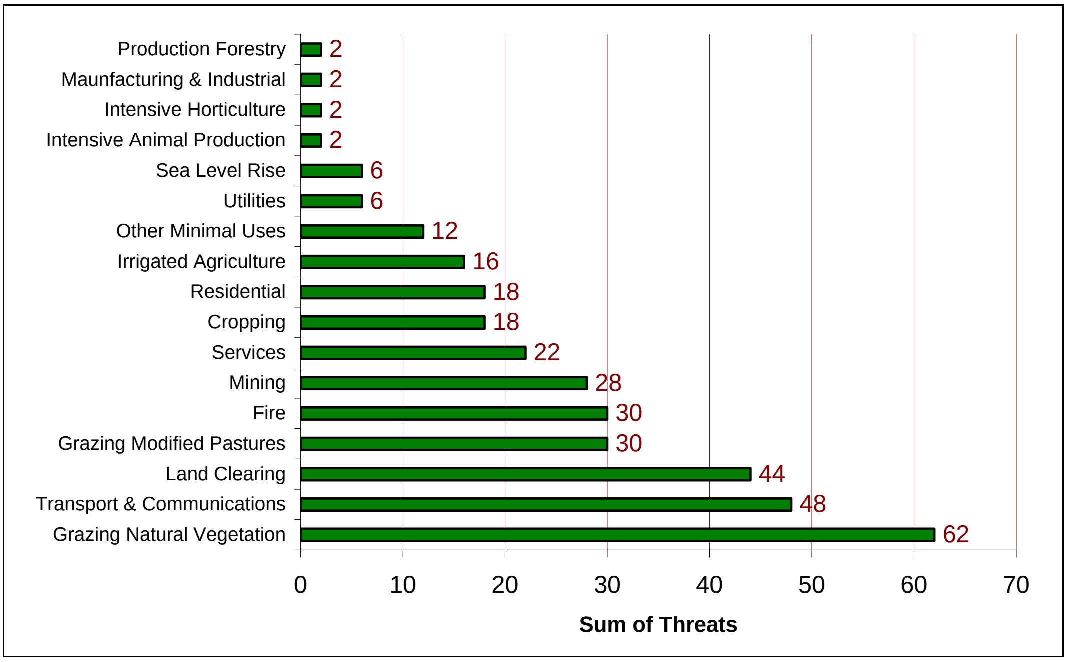


Figure 3.28 Sum of threats for each threat included in the RRM for the Daly River catchment

3.4.5 Ecological Assessment Endpoints

The relative risk scores for the ecological assessment endpoints across the 18 risk regions of the Daly River catchment are shown in Table 3.13. The ecological assessment endpoint with the highest total risk is maintenance of biodiversity (2124). Conversely, the ecological assessment endpoint with the lowest total risk is maintenance of perennial flow (1282).

Figure 3.29 shows the relative risk rankings for the ecological assessment endpoints across the 18 risk regions.

Table 3.13 Ecological assessment endpoint risk ranks for the 18 risk regions within the Daly River catchment.

	Assessment Endpoints				
Risk Region	**Maintenance of perennial flow**	**Water quality**	**Maintenance of riparian vegetation**	**Maintenance of biodiversity**	**Total Risk by Region**
1	114	192	184	216	706
2	20	24	40	60	144
3	120	120	152	180	572
4	108	180	124	168	580
5	96	108	104	120	428
6	84	120	108	176	488
7	84	168	96	124	472
8	0	24	8	8	40
9	104	208	116	152	580
10	108	132	124	200	564
11	120	132	132	164	548
12	84	96	96	148	424
13	60	84	64	84	292
14	24	60	36	52	172
15	24	60	44	52	180
16	36	48	56	52	192
17	96	120	132	164	512
18	0	16	4	4	24
Total Risk for Assessment Endpoint	1282	1892	1620	2124	6918

Table Key

	Nil	Lower	Medium	Higher
Perennial Flow				
Water Quality				
Riparian Vegetation				
Biodiversity				

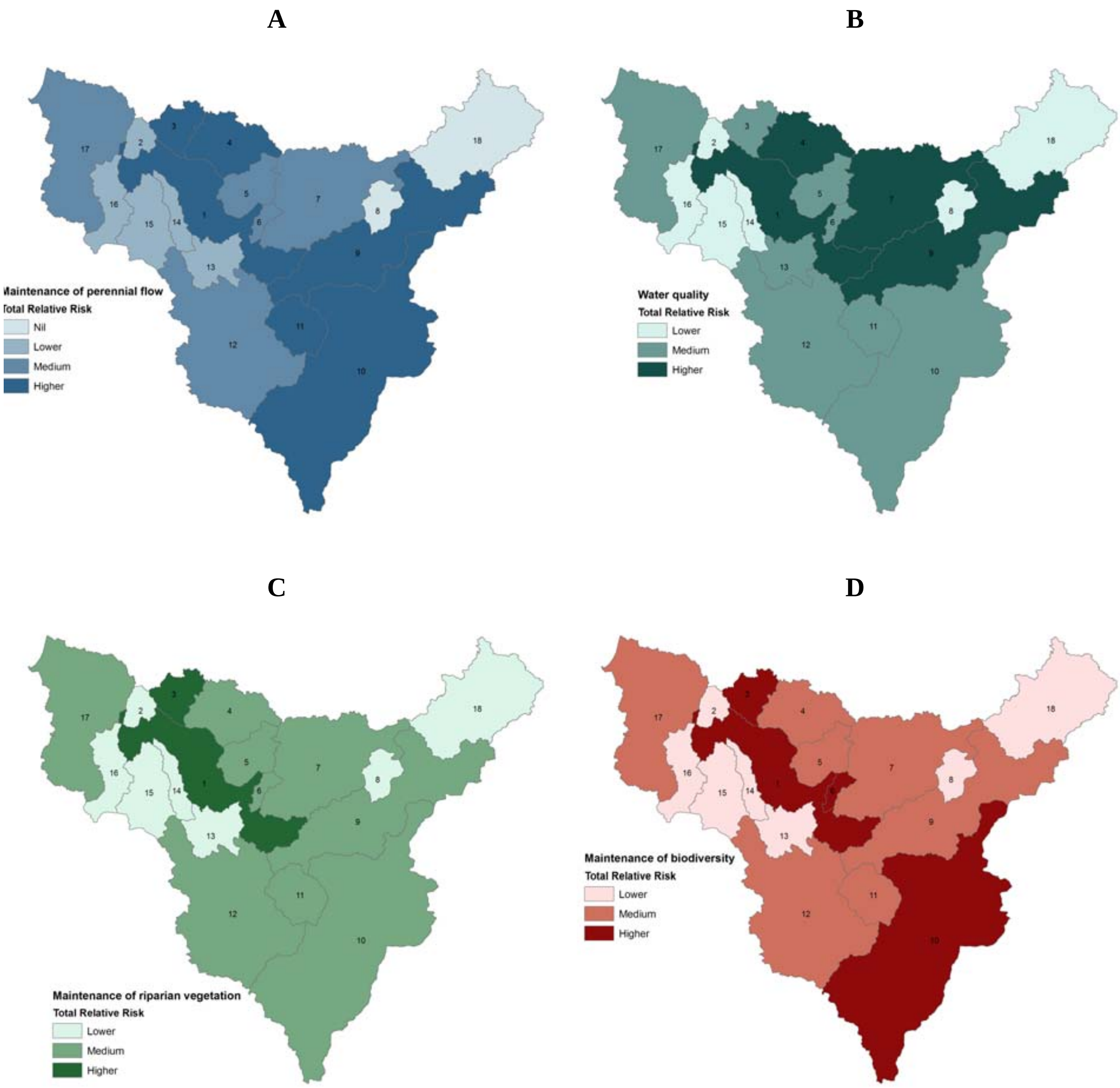


Figure 3.29 Relative risk to ecological assessment endpoints across the (18) risk regions of the Daly River catchment. A – maintenance of perennial flow; B – water quality; C – maintenance of riparian vegetation; and D – maintenance of biodiversity.

The risk regions with the highest total risk for maintenance of perennial flow are: Limestone and Green Ant Creeks (Risk Regions 11 and 3 respectively) – 120; and Daly River (Risk Region 1) – 114. The high total risk scores for Limestone and Green Ant Creeks (Risk Regions 11 and 3 respectively) are the result of high rankings for waterway habitat combined with high scores for altered hydrology and change in groundwater level impacts. These scores are due to high rankings for grazing natural vegetation and land clearing. There are two catchments allocated 'nil' risk for maintenance of perennial flow (Upper Katherine River - Risk Region 18 and Seventeen Mile Creek – Risk Region 8). These 'nil' rankings are due to zero scores for altered hydrology and change in groundwater level impacts to waterway habitats. The zero score for altered hydrology is derived from 'nil' rankings for land clearing and land uses such as grazing natural vegetation and irrigated agriculture. The zero score for change in groundwater level is derived from 'nil' rankings for irrigated agriculture and land clearing.

The risk regions with the highest total risk for water quality are: Katherine River (Risk Region 9) –208; Daly River (Risk Region 1) - 192; and Douglas River (Risk Region 4) – 180. Conversely, the risk regions with the lowest total risk for water quality are: Upper Katherine River (Risk Region 18) – 16; and Hayward and Seventeen Mile Creeks (Risk Regions 2 and 8) - 24. The high total risk scores for the Katherine, Daly and Douglas Rivers (Risk Regions 9, 1 and 4) are associated with high rankings for waterway habitats combined with high scores for altered hydrology and influx of contaminant impacts to waterway habitats. The high scores for altered hydrology are due to high rankings for irrigated agriculture, transport and communications and land clearing for the Katherine Region (Risk Region 9), and grazing natural vegetation, transport and communications and land clearing for Daly and Douglas Rivers (Risk Regions 1 and 4). The pressures/threats contributing to the high scores for influx of contaminants are irrigated agriculture, mining, residential and transport and communications for the Katherine River (Risk Region 9), and cropping and transport and communications in the Daly and Douglas Rivers (Risk Regions 1 and 4).

The lower risk scores for Upper Katherine River (Risk Region 18) and Hayward and Seventeen Mile Creeks (Risk Regions 2 and 8) are because there were many zero risk rankings for the pressures/threats linked to impacts on waterway habitats. Fire was the main input into the risk scores for these risk regions.

The risk regions with the highest total risk for maintenance of riparian vegetation are: Daly River (Risk Region 1) – 184; Green Ant Creek (Risk Region 3) – 152; and Limestone Creek and Daly River Estuary (Risk Regions 11 and 17) (132). The risk regions with the lowest total risk for maintenance of riparian vegetation are: Upper Katherine River (Risk Region 18) – 4; and Seventeen Mile Creek (Risk Region 8) - 8. The high total risk scores for the Daly River (Risk Region 1), Green Ant Creek and Limestone Creeks (Risk Regions 3 and 11), and Daly River Estuary (Risk Region 17) are due to high rankings for waterway habitats (there was a variation in rankings from low to high for riparian habitats) combined with high rankings for various pressures/threats. The high scores for altered hydrology impacts to waterways for these four risk regions are due to high rankings for grazing natural vegetation and land clearing, plus transport and communications in the Daly River (Risk Region 1), Limestone Creek (Risk Region 11) and Daly River Estuary (Risk Region 17). Similarly, the high scores for change in vegetation structure impacts to riparian communities are attributed to high rankings for grazing natural vegetation for the Daly River (Risk Region 1) and Green Ant and Limestone Creeks (Risk Regions 3 and 11) and grazing modified pastures for the Daly River (Risk Region 1) and Daly River Estuary (Risk Region 17). In contrast, the risk regions with the lower total risk for maintenance of riparian vegetation, have pressures/ threats with a 'nil' ranking.

When assessing maintenance of biodiversity, the risk regions with the highest total risk are: Daly River (Risk Region 1) – 216; King and Dry Rivers (Risk Region 10) – 200; and Green Ant Creek (Risk Region 3) – 180. The high risk scores are associated with high scores for altered hydrology impacts for waterways, change in vegetation structure and reduction in habitat for flora and fauna for riparian habitats, and reduction in habitat for flora and fauna for wetland habitat. High scores for altered hydrology impacts were due to high rankings for grazing natural vegetation in the three risk regions, and with high rankings for land clearing for the Daly River (Risk Region 1) and Green Ant Creek (Risk Region 3). Grazing natural vegetation was also highly ranked for impacts on riparian habitats. The risk regions with the lowest total risk are Upper Katherine River (Risk Region 18) – 4 and Seventeen Mile Creek (Risk Region 8) – 8. The lower risk scores are due low or 'nil' risk rankings for pressures/threats.

3.5 Sensitivity Analysis

This section presents the results of the four sensitivity tests that were undertaken on various components of model input and output. We reiterate here that some of these tests were performed on earlier iterations of the RRM than the results reported in Sections 3.3 and 3.4.

3.5.1 Combining ecological assessment endpoints

The original Daly River RRM included maintenance of aquatic threatened species as an assessment endpoint. As discussed previously, this endpoint has the same exposure and effects pathways resulting in the same scores for each risk region as the water quality endpoint. As aquatic threatened species are dependent on water quality (and possibly also the other ecological assessment endpoints), the stability of the model was examined after collapsing the two endpoints into one (ie. water quality). Figure 3.30 illustrates the total relative risk scores for the combined assessment endpoints (ie. maintenance of aquatic threatened species + water quality). Figure 3.31 illustrates the total relative risk scores for the model with the collapsed endpoints (basically water quality).

As shown in Table 3.31 there was very little change in the rankings of risk regions between the two models based on their total relative risk scores. The majority either were ranked the same or differed by only one rank. In two instances (Risk Regions 3 [Green Ant Creek] and 16 [Chilling Creek]) the difference in rank was two. These changes in ranks are not significant as no risk region changed from being a low risk rank to a high risk rank (or vice-versa), thereby indicating the model is relatively stable when collapsing two similar endpoints into one.

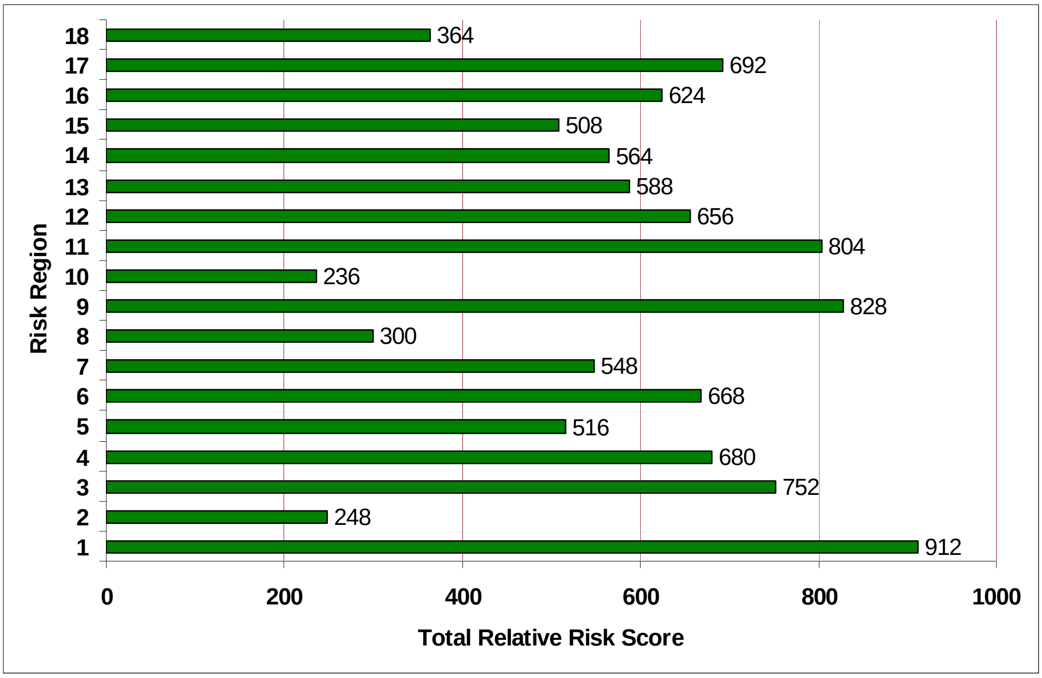


Figure 3.30 Relative Risk Scores prior to merging ecological assessment endpoints

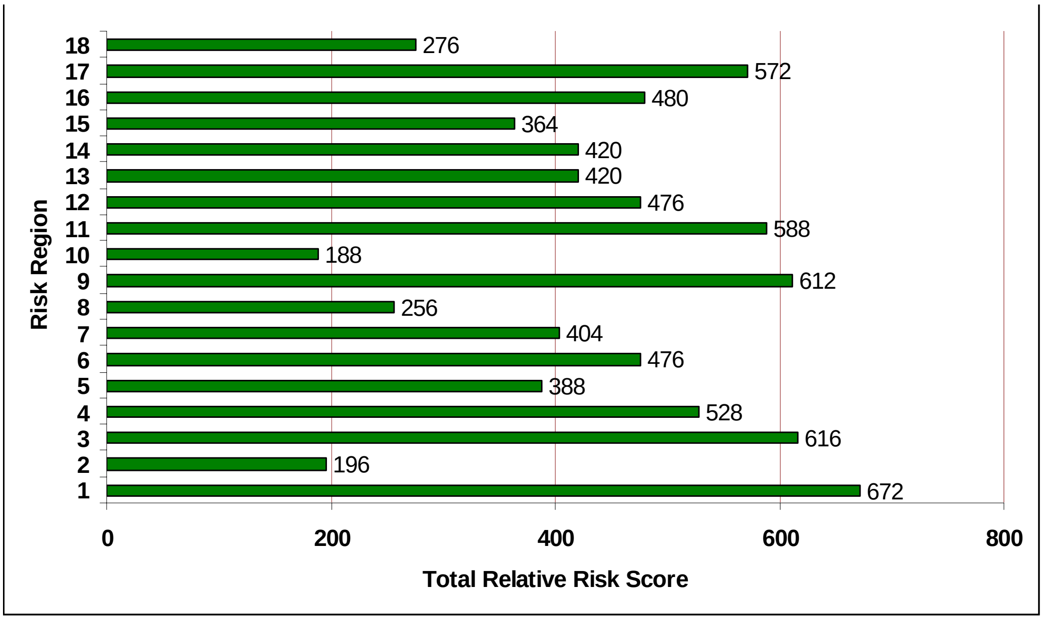


Figure 3.31 Relative Risk Scores after merging ecological assessment endpoints

Table 3.12 Comparison of Total Relative Risk Scores before and after merging ecological assessment endpoints (Ranks in blue within the total risk columns)

Risk Region	Assessment endpoints						
	Maintenance of perennial flow	**Water quality**	**Maintenance of aquatic threatened species**	**Maintenance of riparian vegetation**	**Maintenance of biodiversity**	**Total Risk by Region**	**Total Risk for Merged Endpoints**
1	120	240	240	152	160	912 [1]	672 [1]
2	28	52	52	44	72	248 [17]	196 [17]
3	96	136	136	144	240	752 [4]	616 [2]
4	80	152	152	112	184	680 [6]	528 [6]
5	80	128	128	96	84	516 [13]	388 [13]
6	96	192	192	108	80	668 [7]	476 [8]
7	56	144	144	80	124	548 [12]	404 [12]
8	20	44	44	44	148	300 [16]	256 [16]
9	88	216	216	112	196	828 [2]	612 [3]
10	24	48	48	36	80	236 [18]	188 [18]
11	132	216	216	148	92	804 [3]	588 [4]
12	96	180	180	112	88	656 [8]	476 [9]
13	84	168	168	96	72	588 [10]	420 [10]
14	72	144	144	96	108	564 [11]	420 [11]
15	72	144	144	84	64	508 [14]	364 [14]
16	72	144	144	112	152	624 [9]	480 [7]
17	64	120	120	112	276	692 [5]	572 [5]
18	40	88	88	56	92	364 [15]	276 [15]
Total Risk for Assessment Endpoint	1320	2556	2556	1744	2312	10488	7932

3.5.2 Use of hectares compared with percentage of area cover

The habitat and pressure/threat ranking tables in Sections 3.3. and 3.4 display risk ranking results based on both percentage cover and hectares. Rankings will vary depending on the unit used. However, by using percentage cover the rankings are normalised by risk region area. The use of either unit depends on the research question being addressed.

Figure 3.32 illustrates the difference in using percentage cover compared with hectares for sea level rise vulnerability across the Northern Tropical Rivers. In this example, there is one instance (risk region 10) where the risk ranking went from lower (for percentage cover) to higher (for hectares). Risk regions 8, 11, 25, 32, 37, 39, 40 and 41 went from a ranking of lower (for percentage cover) to medium (for hectares). Risk region 36 went from a ranking of medium (for percentage cover) to higher (for hectares). This example highlights the difference between using the two units for calculating relative risk. For questions around which catchments contain the largest areas of wetland vulnerable to sea level rise, the hectare based approach may be more appropriate.

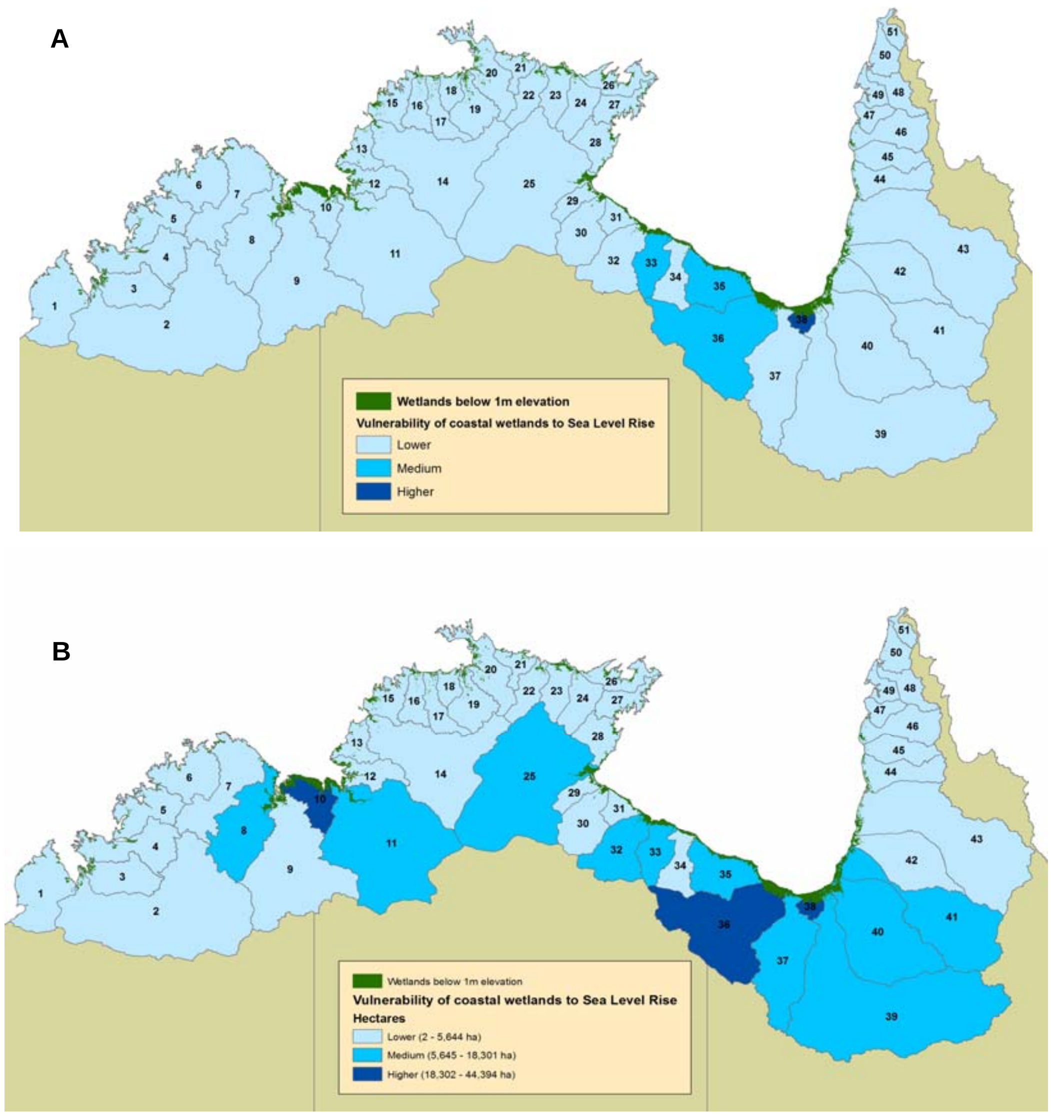


Figure 3.32 Relative Risk rankings for vulnerability of costal wetlands to sea level rise. A – Risk ranking based on percentage area cover; and B – Risk ranking based on number of hectares

3.5.3 Stakeholder ranking analysis

The results of the stakeholder interval analysis are shown in Table 3.13(a-c). A comparison of the minimum and maximum interval ranks for the five selected risk regions indicates that the RRM is representative of stakeholder perceptions of interaction betweens pressures/threats and habitats. The minimum interval risk ranks are the same as the risk ranks resulting from the RRM (refer to Table 3.13). The maximum interval risk ranks only differ from the RRM risk ranks for Risk Regions 1 and 9 (refer to Table 3.15). Risk Region 1 (Daly River) is ranked as number one in the maximum interval analysis and number two in the RRM, whilst Risk Region 9 (Katherine River) is ranked as number two in the maximum interval analysis and number one in the RRM. These rank changes are not significant and do not indicate instability in the RRM as there were no risk regions that went from a higher rank to a lower rank (ie. from a rank of one or two to a rank of four or five). The ranking of assessment endpoints remained unchanged between the minimum and maximum interval analyses and the RRM. Figure 3.33 presents a comparison of stakeholder perceptions derived from the interactions represented in the RRM.

In addition to demonstrating that the RRM is relatively robust to innate and extreme (minimum to maximum) differences in stakeholder perceptions of the magnitude of effects given the same exposure level, results can be expressed with uncertainty bounds. For example, risk region 1 ranked between 1st and 2nd place in terms of total risk. Another method to capture model and parameter uncertainty in the RRM not trialled here is Monte Carlo simulation, given an assumed distribution of risk scores among stakeholder assessors. The fixed risk rank value derived by the RRM calculations is replaced with a mean value derived from a large number of random draws. Hence, the uncertainty bounds would reduce because they now have a central tendency rather than a probability of occurring between a minimum and maximum range (see Hayes & Landis 2004).

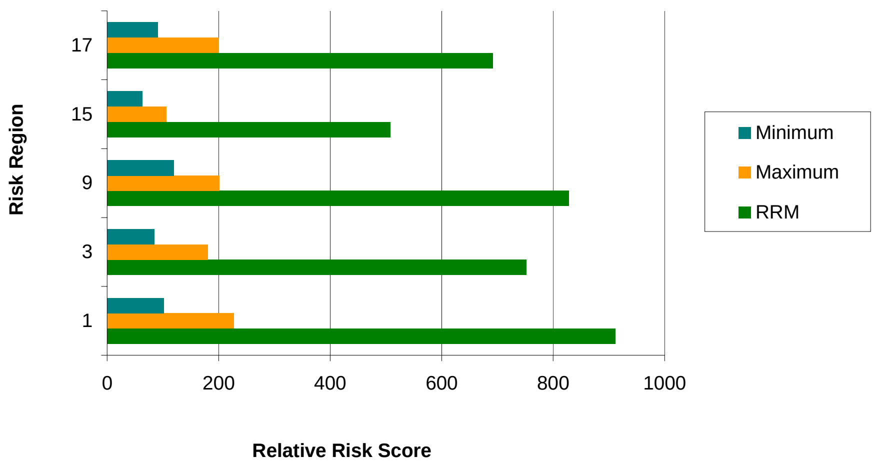


Figure 3.33 Comparison of stakeholder perceptions of interactions within the RRM

3.5.4 Use of particular spatial data

Riparian spatial data for the Daly River catchment

To test the importance of selecting the most appropriate spatial data for input into the RRM, a comparison of riparian datasets for the Daly River catchment was conducted. Specifically, changes in rank of the extent of riparian habitats mapped from the Melaleuca Survey 1993 and NVIS 2005 datasets, and comparison of hectares with percentage areal cover, were determined as shown in Figures 3.34 and 3.35.

Table 3.13(a) Minimum interval analysis for five risk regions in the Daly River catchment

Assessment Endpoints	Maintenance of perennial flow	Water quality	Maintenance of aquatic threatened species	Maintenance of riparian vegetation	Maintenance of biodiversity	Total Risk by Region		
Risk Region							**Minimum Interval Rank**	**RRM Model Rank**
1	11.04	25.44	25.44	18.24	21.6	**101.76**	2	2
3	7.76	14.4	14.4	17.72	30.84	**85.12**	4	4
9	11.76	32.16	32.16	17.28	27	**120.36**	1	1
15	8.4	17.4	17.4	11	9	**63.2**	5	5
17	6.4	13.2	13.2	20.2	38.4	**91.4**	3	3
Total Risk for Assessment Endpoint	**45.36**	**102.6**	**102.6**	**84.44**	**126.84**	**461.84**		
Endpoint Rank	4	2	2	3	1			

Table 3.13(b) Relative Risk Model results for five risk regions in the Daly River catchment

Assessment Endpoints	Maintenance of perennial flow	Water quality	Maintenance of aquatic threatened species	Maintenance of riparian vegetation	Maintenance of biodiversity	Total Risk by Region	
Risk Region							**RRM Model Rank**
1	120	240	240	152	160	**912**	1
3	96	136	136	144	240	**752**	3
9	88	216	216	112	196	**828**	2
15	72	144	144	84	64	**508**	5
17	64	120	120	112	276	**692**	4
Total Risk for Assessment Endpoint	**440**	**856**	**856**	**604**	**936**	**3692**	
Endpoint Rank	4	2	2	3	1		

Table 3.13(c) Maximum interval analysis for five risk regions in the Daly River catchment

Assessment Endpoints	Maintenance of perennial flow	Water quality	Maintenance of aquatic threatened species	Maintenance of riparian vegetation	Maintenance of biodiversity	Total Risk by Region		
Risk Region							**Maximum Interval Rank**	**RRM Model Rank**
1	26.16	57.24	57.24	43.92	42.96	**227.52**	**1**	2
3	17.36	25.6	25.6	45.8	66.28	**180.64**	**4**	4
9	19.04	54.48	54.48	29.28	44.36	**201.64**	**2**	1
15	15.6	27	27	20.8	15.84	**106.24**	**5**	5
17	14	30	30	41.6	85.2	**200.8**	**3**	3
Total Risk for Assessment Endpoint	**92.16**	**194.32**	**194.32**	**181.4**	**254.64**	**916.84**		
Endpoint Rank	4	2	2	3	1			

When comparing rank changes for number of hectares compared with percentage cover for the Melaleuca Survey 1993 data, in most instances percentage cover ranks were higher where ranks changed by two levels (Figures 3.34 A and 3.35 A-B). For the same comparison using the NVIS 2005 data, in all but three risk regions there were no changes in rank. In the three risk regions where ranks changed, they changed by only one rank (Figures 3.34 B and 3.35 C-D). These results indicate that the NVIS 2005 data are not as dependent as the Melaleuca Survey 1993 data on whether or not ranks are generated from number of hectares or percentage cover and, therefore, is likely a more robust dataset for input into the RRM.

When comparing ranks generated from number of hectares with ranks generated from percentage cover for the two datasets, it is evident that the number of hectares is less affected by dataset selection. Ranks were the same for 13 out of the 18 risk regions, and those ranks that did differ did so by only one rank (Figure 3.34 C). In contrast, ranks generated from percentage cover resulted in rank changes in 15 out of the 18 risk regions, with a rank change of two in four of these regions. These results suggest that if the reliability or robustness of the riparian datasets was not known, that ranks generated from the number of hectares are less affected than those generated from percentage cover.

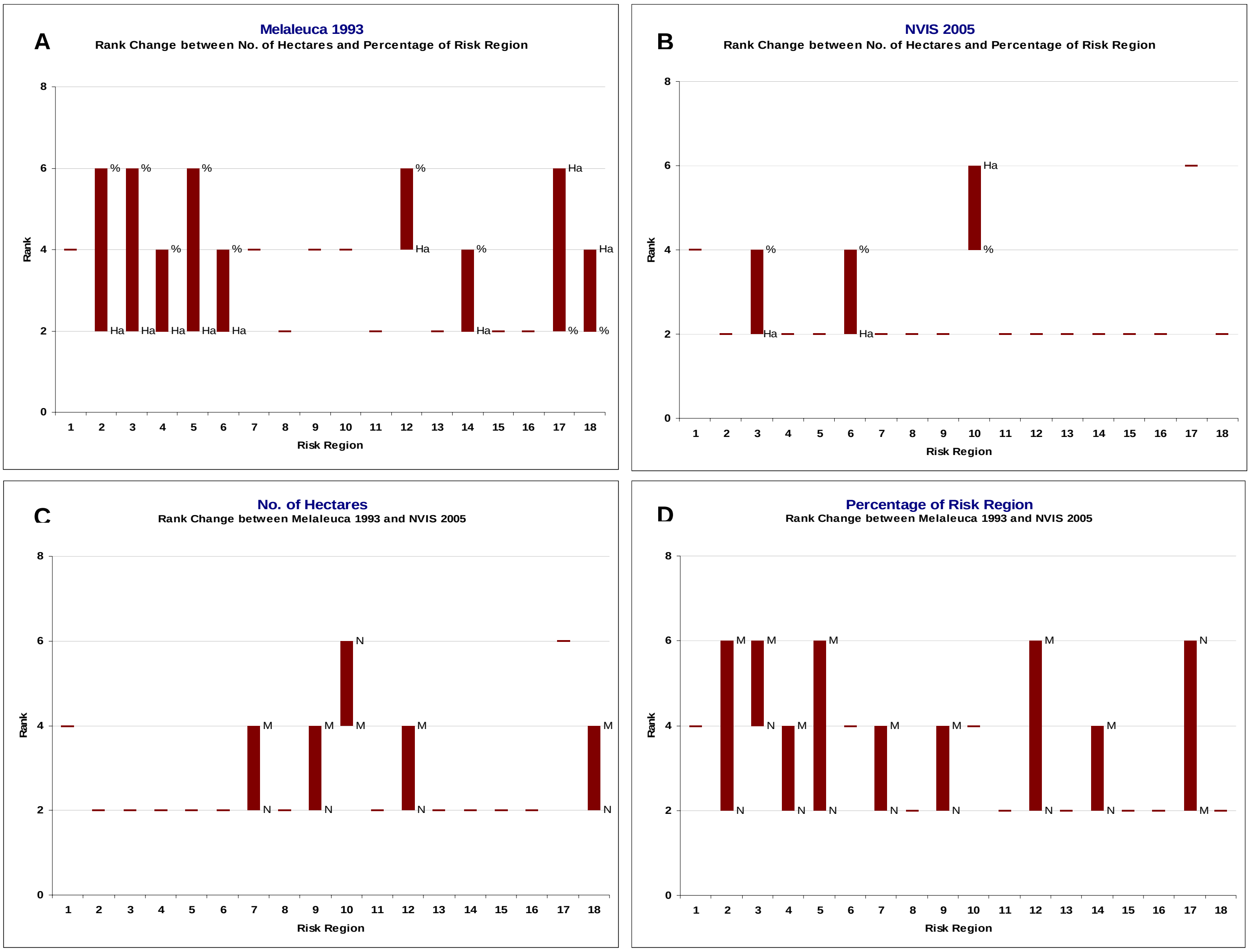


Figure 3.34 Comparison of Melaleuca Survey (1993) and NVIS 2005 riparian data for rankings in the RRM. A – Melaleuca Survey 1993 rank change between number of hectares and percentage cover of risk region; B – NVIS 2005 rank change between number of hectares and percentage cover of risk region; C – Comparison of rank change for number of hectares between the two data sets; and D – Comparison of rank change for percentage cover between the two data sets.

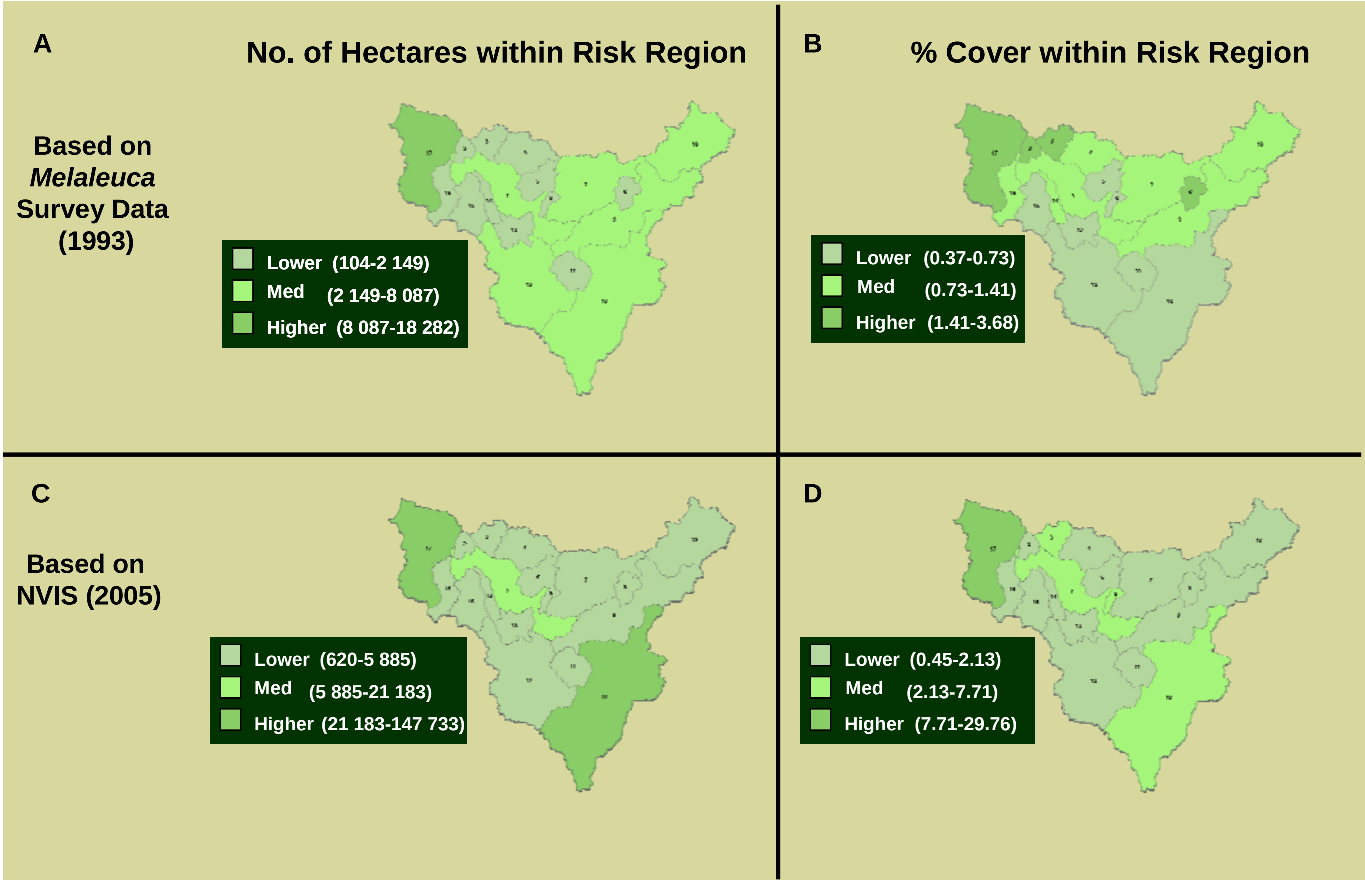


Figure 3.35 Graphical comparison of Melaleuca Survey (1993) and NVIS 2005 riparian data for rankings in the RRM. A – Melaleuca Survey 1993 rankings based on number of hectares; B – Melaleuca Survey 1993 rankings based on percentage cover; C – NVIS 2005 rankings based on number of hectares; and D – NVIS 2005 rankings based on percentage cover.

3.6 Discussion

3.6.1 Issues in defining ecological assessment endpoints

Definition of ecological assessment endpoints is a crucial step in the risk assessment process. Table 3.14 summarises the problems inherent in selecting ecological assessment endpoints. Based on US EPA (1998), the ecological assessment endpoints selected in this study are not specific and represent management goals rather than assessment endpoints. This is primarily due to the use of the term 'maintenance' which represents a goal. The use of stakeholder reports on ecological values to derive assessment endpoints led to vague articulation and definition. 'Maintenance' is a subjective term that is difficult to define as it represents a different meaning for different people.

It is difficult to create assessment endpoints for ecological values centred on habitat conservation. A solution for the biodiversity endpoint may be to select a keystone species from the system and build an assessment endpoint around a lifecycle attribute such as nesting or survival. For the riparian vegetation endpoint, community structure and habitat value to riparian wildlife species could have been stipulated.

The use of multiple assessment endpoints is in congruence with US EPA (1998). This approach is more effective than using a single endpoint due to the multiple pressures/threats effecting both aquatic and terrestrial components of the system.

Table 3.14 Problems inherent in defining ecological assessment endpoints (US EPA 1998:40)

Endpoint is a goal (eg. maintain and restore endemic populations)
Endpoint is vague (eg. estuarine integrity instead of eelgrass abundance and distribution)
Ecological entity is better as a measure (eg. emergence of midges can be used to evaluate an assessment endpoint for fish feeding behaviour)
Ecological entity may not be as sensitive to the stressor (eg. catfish versus salmon for sedimentation)
Ecological entity is not exposed to the stressor (eg. using insectivorous birds for avian risk of pesticide application to seeds)
Ecological entities are irrelevant to the assessment (eg. lake fish in salmon stream)
Importance of a species or attributes of an ecosystem are not fully considered (eg. mussel-fish connection)
Attribute is not sufficiently sensitive for detecting important effects (eg. survival compared with recruitment for endangered species)

3.6.2 Uncertainty

The sensitivity analyses described in Section 3.5 test some of our assumptions of uncertainty with a particular focus on data as this is a key input into the RRM. The focus of this study was to trial the RRM and develop tests for sensitivity analyses that suited the goals of the project. Further work is required to quantify uncertainty in a meaningful way, and this is perhaps one of the most difficult tasks in an ecological risk assessment. Sources of uncertainty for selected model parameters (habitats and pressures/threats) and a qualitative ranking of the uncertainty level for the Northern Tropical Rivers scale is presented in Appendix 3. This section further describes qualitatively sources of uncertainty.

Uncertainty in conceptual models

Uncertainty related to conceptual model structure is a critical component in the risk assessment process because if key relationships are not included or are incorrect, risks may be misrepresented (US EPA 1998). Sources of uncertainty in the development of conceptual models in this study are: lack of knowledge; omission of pressures/threats; misrepresentation of effect pathways; and over-simplification.

The pathways between effects and exposure for the conceptual models developed at both scales in this study were derived from existing information and expert opinion. There is an element of investigator bias (Weigers et al 1998) contributing to uncertainty, whereby not all sources of information may have been located and used. In the Daly River catchment conceptual model, the invasive species pressures/threats were omitted as suitable regional-scale spatial data were not available to represent these key components in the RRM. In the Northern Tropical Rivers conceptual model, land clearing was omitted for the same reason. By their very nature, conceptual models are subject to simplification, which is evident in the example from the Daly River catchment. A series of component conceptual models, representing detail for habitat degradation, perennial stream flow and sedimentation, were combined into a single conceptual model for the RRM. In order to combine these models simplification was a necessary pre-requisite and, hence, some key pathways may have been omitted. The stakeholder interval analysis could be further explored to quantify uncertainties around perceptions of interactions (i.e. large ranges in intervals indicate a larger degree of uncertainty).

Uncertainty was reduced for the Daly River catchment conceptual model by presenting it to technical experts for refinement. This addressed issues of investigator bias and information gaps.

Uncertainty in spatial data

The inclusion of spatial data in ecological risk assessment contributes to the overall uncertainties inherent in site-specific through to regional scale risk assessments (Woodbury 2003). The uncertainty in this instance arises from an inability to fully resolve the spatial heterogeneity of parameters such as land use and vegetation due to scale (Obery and Landis 2002), error propagation through analysis (Woodbury 2003), and aggregation of spatial data (Hession et al 1996; Woodbury 2003).

The uncertainty related to spatial data can be quantified in some instances where error matrices on spatial data derived from remotely-sensed imagery are available. In the example of the Northern Territory Land Use Mapping data, such an error matrix exists for the majority of the individual land classes. This classification error could be reported for each of the land use pressures/threats in the Daly River catchment RRM with some further analysis, and we recommend this for future assessments using the RRM.

In deriving the riparian dataset it became apparent that there are some areas across the Northern Tropical Rivers study area where there are high levels of uncertainty. For northern coastal Western Australia, for example, there are a number of risk regions where there are no riparian data mapped from the NVIS dataset despite there being knowledge that riparian habitat exists in this region. For the Queensland riparian data there are tiles where riparian habitat may be underestimated, or overestimated, as the data is a composite of four datasets. There is a lower degree of uncertainty for the riparian data in the Northern Territory and the Daly River catchment.

There is also uncertainty around the land use mapping data. Some land uses known to occur in risk regions have not been mapped through ACLUMP. This may be related to issues of scale, paucity of verification data or the fact that some of the datasets are 10 years old. There are incidences of overestimation of the areal extent of land uses, for example, horticulture in the Daly River catchment.

There is a low degree of uncertainty on core datasets such as the waterways and wetlands. These data are derived from national datasets (1:250 000 scale) that users have a high degree of confidence in and are regularly maintained. There is a 1:50 000 scale wetland dataset for the Daly River Basin (Begg et al. 2001), which covers a portion of the Daly River catchment. This dataset is further discussed in Chapter 5.4.

3.6.3 Use of spatial data

The application of the RRM is only as good as the input data. Unlike southern Australia, there is limited detailed spatial data available for northern Australia, with most datasets derived from Commonwealth mapping programs. Following is an identification of key information gaps that are limitations on the application of the RRM in this study.

Identification of spatial datasets that may be used to represent gaps or improve existing knowledge

Land clearing data was a key gap at the Northern Tropical Rivers scale. Detailed land clearing mapping is undertaken and updated by the three jurisdictions within the region. The land clearing data was readily available for the Northern Territory, but we had difficulties in obtaining a similar dataset for Western Australia and Queensland (although we know such a dataset exists for Queensland). A recommendation from this study is that land clearing data for Western Australia and Queensland are obtained so that land clearing can be incorporated in the RRM at the Northern Tropical Rivers scale.

The representation of invasive species threats could also be improved at the Northern Tropical Rivers scale. The spatial data used was broad-scale and from 2001. Considerable changes in the distribution of invasive species have occurred since that time (Rossiter et al. 2003; Woinarksi et al. 2007). The incorporation of weed and feral animal distribution and abundance data into the RRM could be improved, and the associated uncertainty reduced, through deriving or sourcing habitat suitability maps (particularly for weed species). Invasive species were not incorporated in the Daly River RRM as there were no suitable catchment-wide spatial datasets available (Section 3.3.2). This is a key information gap that creates a high degree of uncertainty in the model as invasive weeds are a key threat in the region. Nevertheless, there exist excellent distribution and abundance maps for two key wetland weed species on the Daly River floodplain for 2003, and which were used to undertake a comprehensive spatially-explicit ERA using up-dated information provided by the NT government's Weeds Branch (Section 4.2.4).

Pressures/threats from recreational activities such as fishing were not incorporated in the RRM at both scales as these data do not exist in a spatial form. The addition of such a dataset would be of particular use for the Daly River catchment where expert stakeholders raised the need to assess potential impacts on aquatic habitats from recreational fishing and boating activities. Recreational fishing in the Daly River is addressed in Chapter 4 (Section 4.3.4). However, apart from Tour boat operators in the NT who are required to fill out log books of catch by fishing zone, catch-effort data obtained for the majority of recreational fishing pressure obtained questionnaire surveys does not report precise locations bur rather by river and, at best, river reach where there are restricted fishing areas.

3.6.4 Utility of the RRM: Advantages and limitations in the application to tropical rivers ecological risk assessment

The advantages and limitations of the RRM are summarised in Table 3.15. This section will review these advantages and limitations in the context of ecological risk assessment for tropical rivers.

Advantages

Firstly the RRM provides a robust framework for risk assessment, particularly at the regional scale. For the Northern Tropical Rivers scale (51 risk regions) there were no suitable alternatives for conducting an ecological risk assessment across such a large and data-poor area that examines the effect of multiple pressures/threats on multiple ecological assets. As stated by Walker et al (2001), the RRM primarily provides a framework for data collection and decision making, and for preliminary risk assessments that enables collation of information and provides for a stakeholder focus. Through the application of the RRM at both scales in this project, spatial data were collected. From these data, information about pressures/threats and ecological assets were easily summarised, a useful task in itself as this information had not been collated previously in such a manner.

A major advantage of the RRM is the ability to output maps of relative risk. These maps are easily understood by stakeholders from a diverse range of backgrounds and facilitates communication among stakeholders. This is particularly important for our northern rivers because there are many indigenous stakeholders and English is often not their primary language. In this study we produced relative rank maps not only for total relative risk, but in displaying distribution of pressures/threats, the extent of habitat under threat and, total risk to assessment endpoints as ranked through the model. The ability to produce these maps enables stakeholder engagement to continue after conceptual model development.

As for other studies that have used the RRM, we found that its application facilitated discussion between risk assessors, other experts and stakeholders. The transparent nature of the RRM and its simplicity in calculations enables relevant experts to readily understand how relative risks have been derived and enables them to contribute to further model refinement. Due to this and the ability to output maps, we also discovered the RRM provides a high level screening tool for decision makers, particularly in government. For tropical rivers in Australia, where there will be increased development in the future, the RRM application has focused the information we do have and highlights also gaps in knowledge. It has also highlighted regions where there is higher overall risk and, hence, where further studies should be directed. This is the real advantage of the RRM.

Additionally, the RRM is flexible and can be readily updated as more information becomes available and/or risk conditions inevitably change over time. This was demonstrated through the number of iterations we undertook in this study as we located more spatial data for pressures/threats that we did not initially have access to. For example, as updated datasets on land clearing become available we will be able to readily update the RRM.

Other advantages include the ability of the RRM process to generate testable hypotheses about cause-effect relationships between threats and assets, and its ability to capture and make explicit model and parameter uncertainties.

Limitations

The use of areal extent of habitats as a measure of exposure to a pressure/threat may underestimate risk for regions where there are comparatively smaller areal extents of habitat (Hayes and Landis 2004). The assumption is that risk regions with a larger areal extent of habitat receive a high rank indicating there is a high impact to endpoints. This may not be the case and Hayes and Landis (2004) suggest that if there are more data available other than habitat extent, location and quality, then an alternative ranking scheme for habitats should be employed. In their study, they tested an alternative ranking scheme that assumes:

- A small habitat size may mean that populations within the habitat are likely to be more susceptible, due to geographic restriction, to the effects of pressures/threats; and
- The likelihood that the same level of exposure may have greater effects on smaller habitats than larger habitats as the concentration of pressures/threats is proportionally greater.

In the context of the Northern Tropical Rivers application, as there are no further data in most instances apart from habitat extent and location, the alternative ranking method is not warranted. However, due to the large areal extent of risk regions at the Northern Tropical Rivers scale (the risk regions are catchments), the distribution of habitat (patch size) may be an important factor in determining the effects of pressure/threats that have not been captured. Perhaps the Northern Tropical Rivers study area should have been divided into risk regions based on sub-catchments in order to address this. But, in doing so the computations within the application of the RRM would increase significantly.

The ability to incorporate spatial data as a major data input to the model is a key advantage of the RRM approach. However, there are some caveats with using spatial data in the approach. Firstly, spatial data may not represent the true nature of pressures/threats and habitats. Spatial data are a representation often based on the data creator's subjective interpretation. In addition, the spatial data may not be current or maintained and so may not adequately represent current pressures/threats. Secondly, as we have found in this study, if there are no spatial data available for a particular pressure/threat then it is omitted from the RRM creating uncertainty.

Other caveats relate to the model itself: uncertainty is created when interactions between pressures/threats and habitats are not well understood; the complexity of interactions can be oversimplified as they are being collapsed into one rank; the model is based on an additive approach to risk when some pressures/threats may be multiplicative or cumulative in their effect; and, lastly, the ranks and risk scores are relative rather than absolute.

There are some limitations around communication of the RRM to relevant stakeholders. Firstly, the relative ranks developed for one regional model are not transferable and so cannot be compared with the relative ranks from another regional model. Secondly, the information key to the development of a risk score is not clearly evident. In this study we have attempted to address this by summarising and critiquing the spatial data inputs. Thirdly, it is difficult to quantify the uncertainty of ranks. These are more readily addressed qualitatively and to quantify such uncertainty requires further research in spatial statistics. Lastly, but most importantly, ranks may be misinterpreted and used inappropriately. Higher risk does not necessarily mean high risk. Higher risk refers to a comparison of risk between the risk regions within the model, therefore, one risk region is at a higher risk only relative with another in the same risk domain. This may be addressed by including an explicit fitness for purpose status that describes the limitations of the model and the applications it may be specifically used for.

Table 3.15 Summary of the advantages and limitations of the RRM

Advantages	Limitations
Robust framework for ERA at the regional scale (Hart Hayes and Landis 2004;Obery and Landis 2002; Walker et al. 2001; Weigers et al 1998)	Data input (spatial) may not represent the true nature of the pressures/threats and habitats and may require weighting factors to be representative (Colnar and Landis 2007)
Enables multiple pressures/threats to be assessed against multiple ecological assets (assessment endpoints) (Weigers et al. 1998)	Interactions between pressures/threats and habitats may not be well understood either because of a lack of site specific data or a lack of appropriate literature.
Facilitates discussion between risk assessors, stakeholders and decision makers (Walker et al. 2001)	Ranks and risk scores are relative- does not provide an estimate of absolute risk. Relative rankings can be calibrated if exposure-effect data are available for one or more of the endpoints (Weigers et al. 1998)
Provides a valuable tool for planning fieldwork and ground-truthing projects (Walker et al. 2001)	Relative ranks from one regional model can not be compared with relative ranks from another regional model (Weigers et al. 1998) unless both sites are part of the same set of assessment criteria.
Graphical output (maps) through risk characterisation process (Hart Hayes and Landis 2004; Moraes et al. 2002; Obery and Landis 2002)	Information critical to the development of a risk score is not readily evident in the output (Weigers et al. 1998)
Facilitates stakeholder engagement (Obery and Landis 2002)	Difficult to quantify uncertainty around ranks within the model typically requiring a Monte Carlo or similar approach to address (Hart Hayes and Landis 2004)
Provides a high level screening tool for decision makers (Moraes et al. 2002)	Relying on habitat measures as a surrogate for exposure may underestimate risk in risk regions with comparatively small extents of habitat (Hart Hayes and Landis 2004)
Focuses further research (Moraes et al. 2002)	Can oversimplify the complexity of interactions (Obery and Landis 2002)
Easy to understand and straight forward output (Landis and Weigers 1997)	Ranks may be misinterpreted and used inappropriately (Landis and Weigers 1997)
Flexible and can be modified to suit the ecological risk assessment focus (Colnar and Landis 2007; Andersen et al. 2004; Obery and Landis 2002)	Assumes an additive approach when some pressures/threats may have multiplicative effects (Andersen et al. 2004)
Generates testable and spatially explicit hypotheses (Weigers et al. 1998; Landis and Weigers 1997)	Requires spatial data to be available for pressures/threats and habitats otherwise they can not be modelled.
Easily updated as more data becomes available allowing alteration of the risk ranks or the uncertainty distributions (Weigers et al. 1998; Landis and Weigers 2005)	Provides an indication of exposure through comparing areal extents of pressures/threats and habitats, but does not characterise the effects component of risk assessment.
Highlights components where uncertainty should be reduced (Moraes et al. 2002)	

3.7 Summary and conclusions

A key challenge in conducting ecological risk assessments at the regional scale is incorporating multiple pressures/threats and their effects pathways on multiple ecological assets over large areas. In this study we have applied the RRM and tested the utility of this tool for ecological risk assessment for tropical rivers at two scales: the Northern Tropical Rivers (51 risk regions) and a focus catchment, the Daly River catchment (18 risk regions). This is the first time the RRM has been applied at the scale of the Northern Tropical Rivers.

The incorporation of stakeholder and expert input resulted in a robust model with respect to effects, which is generally the unknown quantity in all risk assessments, and aided in addressing issues of uncertainty. The inclusion of stakeholders and experts in the process also facilitated and enhanced communication. By using stakeholder and expert opinion, the uncertainty around information gaps and the structure of conceptual models was reduced, particularly in the absence of this input.

The results of the RRM are in agreement with general knowledge of risk to catchments within northern Australia. That is, those risk regions that were ranked as higher risk concord with people's perceptions of risk and general information at hand. The ability to output various components of the RRM as maps facilitates visual communication with stakeholders and decision makers who can readily relate to interpreting a map.

We have found the RRM to be a robust tool for conducting ecological risk assessment in this study. Its value in this particular application is the ability to use the results as a high level screening/prioritisation tool for decision makers, particularly as northern Australia is being considered for various development scenarios. The results from this project will be used by other research programs focussed on the Northern Tropical Rivers.

Some important sources of uncertainty have been addressed for some aspects of this ecological risk assessment using interval maths and sensitivity analysis. However, further work is required to quantify uncertainty in the conceptual models, such as Monte Carlo simulation, and in the use of spatial data. In addition, novel methods for building exposure and effects models for risk analysis need to be explored along with ways to apply weightings and filters to both pressures/threats and effects.

3.8 References

Andersen MC, Thompson B & Boykin K 2004. Spatial Risk Assessment Across Large Landscapes with varied Land Use: Lessons from a Conservation Assessment of Military Lands. *Risk Analysis* 24, 1231-1242.

Aspinall R & Pearson D 2000. Integrated geographical assessment of environmental condition in water catchments: Linking landscape ecology, environmental modelling and GIS. *Journal of Environmental Management* 59, 299-319.

Bartolo R 2006a. *Stakeholder views: Assets and threats to the tropical rivers of the Fitzroy catchment, WA.* Workshop Report, Derby, 17 February 2006. www.environment.gov.au/ ssd/tropical-rivers/pubs/derby-stakeholder-workshop.pdf.

Bartolo R 2006b. *Stakeholder views: Assets and threats to the tropical rivers of the Flinders River catchment, Queensland.* Interim Workshop Report, Richmond, 6 June 2006. www.environment.gov.au/ ssd/tropical-rivers/pubs/richmond-stakeholder-workshop.pdf.

Bartolo R 2007. The status of climate change research in the Kakadu landscape context. In Walden D & Nou S (eds) 2008. *Kakadu National Park Landscape Symposia Series 2007–2009. Symposium 1: Landscape Change Overview*, 17–18 April 2007, South Alligator Inn, Kakadu National Park. Internal Report 532, April, Supervising Scientist, Darwin. Unpublished paper.

Bayliss B, Brennan K, Eliot I, Finlayson CM, Hall R, House T, Pidgeon R, Walden D & Waterman P 1997. *Vulnerability assessment of predicted climate change and sea level rise in the Alligator Rivers Region, Northern Territory Australia.* Supervising Scientist Report 123, Supervising Scientist, Canberra.

Bayliss P, van Dam R, Boyden J and Walden D 2006. Ecological risk assessment of Magela floodplain to differentiate mining and non-mining impacts. In, Evans KG, Rovis-Hermann J, Webb A & Jones DR (eds). ***eriss*** *research summary 2004–2005*. Supervising Scientist Report 189, Supervising Scientist, Darwin NT.

Begg GW, van Dam RA, Lowry JB, Finlayson CM & Walden DJ 2001. *Inventory and risk assessment of water dependent ecosystems in the Daly basin, Northern Territory, Australia*. Supervising Scientist Report 162, Supervising Scientist, Darwin NT.

Billington K 2005. *The River Murray and Lower Lakes Catchment Risk Assessment Project for Water Quality-Concepts and Methods.* Environmental Protection Authority, South Australia.

Blanch S, Rea N and Scott G 2005. *Aquatic conservation values of the Daly River catchment, Northern Territory, Australia.* A report prepared by WWF-Australia, Charles Darwin University and the Environment Centre NT, Darwin. Copies of the report may be downloaded from wwf.org.au or www.ecnt.org.

Bureau of Rural Sciences 2002. *Land Use Mapping at Catchment Scale (Edition 2).* Commonwealth of Australia, Canberra.

Cape York Interim Advisory Group 2004. *Cape York Peninsula Natural Resource Management Plan – Working draft for public consultation*. Cape York Interim Advisory Group, Cairns, Qld.

Clifford PA, Barchers DE, Ludwig DF, Sielken R.L, Klingensmith JS, Graham RV & Banton MI 1995. An approach to quantifying spatial components of exposure for ecological risk assessment. *Environmental Toxicology and Chemistry* 14, 895-906.

Cobb SM, Saynor MJ, Eliot M, Eliot I & Hall R 2007. *Saltwater intrusion and mangrove encroachment of coastal wetlands in the Alligator Rivers Region, Northern Territory, Australia*. Supervising Scientist Report 191, Supervising Scientist, Darwin NT.

Colner A M & Landis W G 2007. Conceptual model development for invasive species and a regional risk assessment case study: The European Green Crab, *Carcinus maenas*, at Cheery Point, Washington, USA. *Human and Ecological Risk Assessment* 13, 120-155.

CSIRO 2007. *Climate change in Australia – Technical Report 2007*. CSIRO and the Australian Bureau of Meteorology. www.climatechangeinaustralia.gov.au/resources.php.

Department of Natural Resources Mines and Energy 2004. *Gulf and Mitchell Agricultural Land and Water Resource Assessment Report*. Integrated Natural Resource Planning (Water Planning) North Region and Water Planning Group (Brisbane), The State of Queensland, Brisbane, Qld.

Department of Natural Resources and Water 2006. *Gulf draft water resource plan economic and social assessment report*. The State of Queensland, Brisbane, Qld.

Diamond JM & Serveiss VB 2001. Identifying Sources of Stress to Native Aquatic Fauna Using a Watershed Ecological Risk Assessment Framework. *Environmental Science & Technology* 35, 4711-4718.

Dixon I, Douglas M, Dowe J & Burrows D 2006. Tropical Rapid Appraisal of Riparian Condition: Version 1 (for use in tropical savannas). *River Management Technical Guideline No. 7.* Land & Water Australia, Canberra.

Dowe J 2008. Riparian vegetation. In *A Compendium of ecological information on Australia's Northern Tropical Rivers. Sub-project 1 of Australia's Tropical Rivers – an integrated data assessment and analysis* eds Lukacs G & Finlayson M. A report to Land & Water Australia. Australian Centre for Tropical Freshwater Research, National Centre for Tropical Wetland Research, Townsville, Qld, in press.

DRCRG (Daly Region Community Reference Group) 2004. *Draft Report*. Darwin, NT.

Ferdinands K, Devonport C & Whitehead P 2001. The use of GIS-based predictive models to examine the potential impact of Para grass *Urochloa mutica* (Forssk) on landscape structure in the Mary River floodplains, NT. *Proceedings of the North Australian Remote Sensing & GIS Conference*, Darwin.

Faulks JJ 1998. *Daly River catchment (Part 1) – an assessment of the physical and ecological condition of the Daly River and its major tributaries*. DLPE Technical Report No TR99/10, Northern Territory Government, Darwin.

Gordon SI & Majumder S 2000. Empirical Stressor-Response Relationships for Prospective Risk Analysis. *Environmental Toxicology and Chemistry* 19, 1106-112.

Gustafson EJ, Murphy NL & Crow TR 2001. Using a GIS model to assess terrestrial salamander response to alternative forest management plans. *Journal of Environmental Management* 63, 281-292.

Hayes E & Landis WG 2004. Regional Ecological Risk Assessment of a Near Shore Marine Environment : Cherry Point, WA. *Human and Ecological Risk Assessment* 10, 299-325.

Hession WC, Storm DE, Haan CT, Burks SL & Matlock MD 1996. A Watershed-Level Ecological Risk Assessment Methodology. *Water Resources Bulletin* 32, 1039-1054.

Hogsett WE, Weber JE, Tingey D, Herstrom A, Lee EH & Laurence JA 1997. An Approach for Characterizing Tropospheric Ozone Risk to Forests. *Environmental Management* 21, 105-120.

Jackson S 2004. *Preliminary report on Aboriginal perspectives on land use and water management in the Daly River region, NT*. CSIRO, Darwin.

Jenks G F & Caspall F C 1971. Error on chloroplethic maps: Definition, measurement and reduction. *Annals of the Association of American Geographers* 61, 217-244.

Kienast F, Brzeziecki B & Wildi O 1996. Long-term adaptation potential of Central European mountain forests to climate change: a GIS-assisted sensitivity assessment. *Forest Ecology and Management* 80, 133-153.

Landis WG & Wiegers JA 1997. Design Considerations and a Suggested Approach for Regional and Comparative Ecological Risk Assessment. *Human and Ecological Risk Assessment* 3, 287-297.

Landis WG & Wiegers JA 2005. Introduction to the Regional Risk Assessment Using the Relative Risk Model. In *Regional Scale Ecological Risk Assessment-Using the Relative Risk Model* ed Landis WG. CRC Press, USA, pp. 11-36.

Lukacs G & Finlayson M (eds) 2008. *A Compendium of ecological information on Australia's Northern Tropical Rivers. Sub-project 1 of Australia's Tropical Rivers – an integrated data assessment and analysis*. A report to Land & Water Australia. Australian Centre for Tropical Freshwater Research, National Centre for Tropical Wetland Research, Townsville, Qld, in press.

McDonald GT & Dawson SJ 2004. *Northern Gulf region, Natural Resource Management Plan*. Tropical Savannas CRC and NGRMG Ltd, Georgetown. September 2004.

McDonald TL & McDonald LL 2002. A new ecological risk assessment procedure using resource selection models and geographic information systems. *Wildlife Society Bulletin* 30, 1015-1021.

Moares R, Landis WG & Molander S 2002. Regional Risk Assessment of a Brazilian Rain Forest Reserve. *Human and Ecological Risk Assessment* 8, 1179-1803.

Moliere D, Lowry J, Staben G & Humphrey C 2006. Flow characteristics of streams in Tropical Rivers Region. *30th Hydrology and Water Resources Symposium*, 4-7 December, Launceston, Tasmania.

Moore R.E 1979. *Methods and Applications of Interval Analysis*. Society for Industrial and Applied Mathematics, Philadelphia.

Morgan G 2001. *Landscape health in Australia: a rapid assessment of the relative condition of Australia's bioregions and subregions*. Environment Australia and the National Land and Water Resources Audit, Canberra, ACT.

MRWMG 2000. *Mitchell River Watershed Management Plan - A strategic and cooperative approach to managing the Mitchell River Watershed for a sustainable future*. Mitchell River Watershed Management Group, Mareeba, Qld.

NT DIPE (Department of Infrastructure, Planning and Environment) 2003. *Draft Conservation Plan for the Daly Basin Bioregion*, Northern Territory Government, Darwin.

Obery AM & Landis WG 2002. A Regional Multiple Stressor Risk Assessment of the Codorus Creek Watershed Applying the Relative Risk Model. *Human and Ecological Risk Assessment* 8, 405-428.

Preston BL & Shackelford J 2002. Multiple Stressor Effects on Benthic Biodiversity of Chesapeake Bay: Implications for Ecological Risk Assessment. *Ecotoxicology* 11, 85-99.

Preston BL, Green D & Pittock B 2006. Climate Change in Northern Australia. Presented at Sharing Knowledge: A Workshop on Climate Change Impacts and Adaptation Strategies for Northern Australian Indigenous Communities, 29-31 March 2006, Darwin, Northern Territory, Australia.

Price P & Lovett S 2002. *Managing Riparian Land. Fact Sheet 1.* Land & Water Australia, Canberra. Available from: http://www.rivers.gov.au/manage/index.htm

Queensland Environment Groups 2006. *Draft Gulf Water Resources Plan - Queensland Environment Groups' submission*. The Wilderness Society, The Australian Conservation Foundation, Queensland Conservation Council and Cairns and Far North Environment Centre. 14 pp.

Ramsar Convention Secretariat 2006. *The Ramsar Convention Manual: a Guide to the Convention on Wetlands (Ramsar, Iran, 1971)*, 4th ed. Gland, Switzerland. Available for download from: http://www.ramsar.org/lib/lib_manual2006e.htm

RNRMCG (Rangelands Natural Resource Management Coordinating Group) 2005. *Draft natural resource management strategy – rangelands region of Western Australia*. Canning Vale, Western Australia.

Rossiter NA, Setterfield SA, Douglas MM & Hutley LB 2003. Testing the grass-fire cycle: alien grass invasion in the tropical savannas of Northern Australia. *Diversity and Distributions* 9, 169-176.

Rouget M, Richardson, DM, Nel JL & Van Wilgen BW 2002. Commercially important trees as invasive aliens-towards spatially explicit risk assessment at a national scale. *Biological Invasions* 4, 397-412.

Russell-Smith J & Edwards AC 2006. Seasonality and fire severity in savanna landscapes of monsoonal northern Australia. *International Journal of Wildland Fire* 15, 1-10

Russell-Smith J, Yates C & Lynch B 2006. Fire regimes and soil erosion in north Australian hilly savannas. *International Journal of Wildland Fire* 15, 551-556.

Serveiss VB 2001. Applying ecological risk principles to watershed assessment and management. *Environmental Management* 29, 145-154.

Southern Gulf Catchments 2005. *The assets, threats and targets of the region*. Book 4, Southern Gulf Catchments Natural Resource Management Plan. Southern Gulf Catchments, Mt Isa, Qld.

Storey AW, Davies PM and Froend RH 2001. *Fitzroy river system: environmental values.* Report prepared for the Waters and Rivers Commission. Perth, Western Australia.

Storey AW 2006. Ecological values of the Fitzroy River with links to indigenous cultural values. In *Kimberley Appropriate Economies Roundtable Forum Proceedings* eds Hill R, Golson K, Lowe PA, Mann MK, Hayes S & Blackwood JE. Convened 11-13 October 2005, Fitzroy Crossing, WA, by the Kimberley Land Council, Environs Kimberley and Australian Conservation Foundation. Australian Conservation Foundation, pp. 47–49.

Suter II GW 1996. *Guide for Developing Conceptual Models for Ecological Risk Assessments*. Oak Ridge National Laboratory, Oak Ridge.

US EPA (U.S. Environmental Protection Agency) 1998. *Guidelines for Ecological Risk Assessment.* EPA/630/R-95/002F. Risk Assessment Forum, Washington, DC, USA.

Walker R, Landis W & Brown P 2001. Developing a Regional Ecological Risk Assessment: A Case Study of a Tasmanian Agricultural Catchment. *Human and Ecological Risk Assessment* 7, 417-439.

Wiegers JK, Feder HM, Mortensen LS, Shaw DG, Wilson VJ & Landis WG 1998. A Regional Multiple-Stressor Rank-Based Ecological Risk Assessment for the Fjord of Port Valdez, Alaska. *Human and Ecological Risk Assessment* 4, 1125-1173.

Winn KO, Saynor MJ, Eliot MJ & Eliot I 2006. Saltwater intrusion and morphological change at the mouth of the East Alligator River, Northern Territory. *Journal of Coastal Research* 22, 137–149.

Woinarski J, Mackey B, Nix H & Traill B 2007. *The nature of Northern Australia: Natural values, ecological processes and future prospects*. ANU E Press, Canberra, ACT.

Woodbury PB 2003. Dos and Don'ts of spatially explicit risk assessments. *Environmental Toxicology and Chemistry* 22, 253-262.

Xu X, Lin H & Fu Z 2004. Probe into the method of regional ecological risk assessment-a case study of wetland in the Yellow River Delta in China. *Journal of Environmental Management* 70, 299-319.

Appendices

Appendix 1: Land Use Definitions and ALUM Classification (Version 5)

C. ALUM Classification v5 - land use class definitions

Five primary levels of land use are distinguished in order of generally increasing levels of intervention or potential impact on the natural landscape. Water is also included in the classification as a sixth primary class. For catchment scale land use mapping currently being coordinated through BRS under AFFA, MDBC and Audit programs, the minimum expected level of attribution is to the tertiary level for 'Conservation and natural environments' and to the secondary level elsewhere (as shown in part D ALUM Classification v5 - summary). Tertiary classes presented here under primary levels 2, 3, 4, 5 and 6 are under continuing development, and are presented as suggestions/recommendations rather than mandatory elements of the classification.

While tertiary level data is valuable in many natural resource planning and management applications, it is expensive to collect. Generally, mapping is completed to the tertiary level only where pre-existing data is available, or where tertiary level information (eg, crop type) is of particular interest to the mapping agency. BRS has tested alternative mapping approaches using geocoded data from the ABS Agricultural Commodities Census (Ag Stats) which could provide a cost-effective basis of mapping some of these data (Randall and Barson 2001).

1. Conservation and natural environments - Land used primarily for conservation purposes, based on the maintenance of the essentially natural ecosystems present.

2. Production from relatively natural environments - Land used primarily for primary production with limited change to the native vegetation.

3. Production from dryland agriculture and plantations - Land used mainly for primary production, based on dryland farming systems.

4. Production from irrigated agriculture and plantations - Land used mostly for primary production based on irrigated farming.

5. Intensive uses - Land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.

6. Water - Water features. Water is regarded as an essential aspect of the classification, but it is primarily a cover type.

(i) CONSERVATION AND NATURAL ENVIRONMENTS

A relatively low level of human intervention, with the anticipated consequence of little change to natural ecosystems. There may be change in the condition of the land in response to natural processes in isolation from any imposed use. The land may be formally reserved by government for conservation purposes, or conserved through other legal or administrative arrangements. Areas may have multiple uses, however nature conservation is the prime use. Some land may be unused as a result of a deliberate decision of the government or landowner, or due to circumstance.

1.1 Nature conservation Tertiary classes 1.1.1 – 1.1.6 are based on the Collaborative Australian Protected Areas Database (CAPAD) classification (Cresswell and Thomas 1997).

1.1.1 Strict nature reserve Protected area managed mainly for science. An area of land possessing outstanding or representative ecosystems, geological or physiological features and/or species, which is available primarily for scientific research and/or environmental monitoring.

1.1.2 Wilderness area Protected area managed mainly for wilderness protection. A large area of unmodified or slightly modified land, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.

1.1.3 National park Protected area managed mainly for ecosystem conservation and recreation. A natural area of land, designated to: a) protect the ecological integrity of one or more ecosystems for this and future generations; b) exclude exploitation or occupation detrimental to the purposes of designation of the area, and c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.

1.1.4 Natural feature protection Protected area managed for conservation of specific natural features. Area containing one or more specific natural or natural/cultural feature which is of outstanding value because of its inherent rarity, representative or aesthetic qualities or cultural significance.

1.1.5 Habitat/species management area Protected area managed mainly for conservation through management intervention. Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species. This may include areas on private land.

1.1.6 Protected Landscape Protected areas managed mainly for landscape conservation and recreation. Area of land where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, cultural and/or ecological value, and often with high biological diversity.

1.1.7 Other conserved area Land under forms of nature conservation protection that fall outside the scope of the CAPAD classification, including heritage agreements, voluntary conservation arrangements, registered property agreements etc.

1.2 Managed resource protection Tertiary classes 1.2.1 – 1.2.4 are based on the CAPAD classification. These areas are managed primarily for the sustainable use of natural ecosystems. This includes areas with largely unmodified natural systems managed primarily to ensure the long-term protection and maintenance of biological diversity, water supply, aquifer or landscape while providing a sustainable flow of natural products and services to meet community needs.

1.2.1 Biodiversity Managed for biodiversity.

1.2.2 Surface water supply Managed as a catchment for water supply.

1.2.3 Groundwater Managed for groundwater.

1.2.4 Landscape Managed for landscape integrity.

1.2.5 Traditional indigenous uses Managed primarily for traditional indigenous use.

1.3 Other minimal use Areas of land that are largely unused (in the context of the prime use) but may have ancillary uses. This may be the result of a deliberate decision by the manager or the result of circumstances. The land may be available for use but for various reasons remains 'unused'.

1.3.1 Defence Natural areas allocated to field training, weapon testing and other field defence uses.

1.3.2 Stock route Stock reserves under intermittent use or unused.

1.3.3 Remnant native cover Land under native cover, mainly unused (no prime use) or used for non-production or environmental purposes eg to conserve native vegetation and wildlife or for natural resources protection.

1.3.4 Rehabilitation Land under rehabilitation or unused because of weed infestation, salinisation, scalding and similar hazards.

(ii) PRODUCTION FROM RELATIVELY NATURAL ENVIRONMENTS

Land generally subject to relatively low levels of intervention. The land may not be used more intensively owing to its limited capability. The structure of the native vegetation generally remains intact despite deliberate use, although the floristics of the vegetation may have changed markedly. Where the native vegetation structure is, for example, open woodland or grassland, the land may be grazed. Where the native grasses have been deliberately and extensively replaced with improved species, the use should be treated under 3. Production from dryland agriculture and plantations.

2.1 Grazing natural vegetation Land uses based on grazing by domestic stock on native vegetation with limited or no attempt at pasture modification. Some change in species composition will have occurred, but the structure of the native vegetation type will be essentially intact.

2.2 Production forestry Commercial production from native forests and related activities on public and private land. Environmental and indirect production uses associated with retained native forest (eg prevention of land degradation, wind-breaks, shade and shelter) are included in an appropriate class under 1. Conservation and natural environments.

2.2.1 Wood production - managed for sawlogs and pulpwood

2.2.2 Other forest production - managed for non-sawlog/pulpwood production, including oil, wildflowers, fire-wood and fence posts.

(iii) PRODUCTION FROM DRYLAND AGRICULTURE AND PLANTATIONS

Land in this class is used principally for primary production, based on dryland farming systems. Native vegetation has largely been replaced by introduced species through clearing, the sowing of new species, the application of fertilisers or the dominance of volunteer species. The range of activities in this category includes plantation forestry, pasture production for stock, cropping and fodder production, and a wide range of horticultural production.

3.1 Plantation forestry Land on which plantations of trees or shrubs (native or exotic species) has been established for production or environmental and resource protection purposes. This includes farm forestry. Where planted trees are grown in conjunction with pasture, fodder or crop production, class allocation should be made on the basis of either prime use or multiple class attribution.

3.1.1 Hardwood production - managed for hardwood sawlogs or pulpwood.

3.1.2 Softwood production - managed for softwood sawlogs or pulpwood.

3.1.3 Other forest production - managed for non-sawlog/pulpwood production, including oil, wildflowers, fire-wood and fence posts.

3.1.4 Environmental - environmental and indirect production uses (eg prevention of land degradation, wind-breaks, shade and shelter).

3.2 Grazing modified pastures Pasture and forage production, both annual and perennial, based on a significant degree of modification or replacement of the initial native vegetation. Land under pasture at the time of mapping may be in a rotation system so that at another time the same area may be, for example, under cropping. Land in a rotation system should be classified according to the land use at the time of mapping. Suggested tertiary classes for legume and grass pasture types can be fitted to the pasture attributes collected through the ABS Agricultural Census.

3.2.1 Native/exotic pasture mosaic Pastures in which there is a substantial native species component despite extensive modification or replacement of native vegetation. This class may apply where native and exotic pasture is patterned at a relatively fine spatial scale.

3.2.2 Woody fodder plants Woody plants used primarily for the purpose of providing forage for livestock grazing. Examples include Tagastaste and Leucaena.

3.2.3 Pasture legumes

3.2.4 Pasture legume/grass mixtures

3.2.5 Sown grasses

3.3 Cropping Land under cropping. Land under cropping at the time of mapping may be in a rotation system so that at another time the same area may be, for example, under pasture. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping can vary markedly over relatively short distances in response to change in the nature of the land and the preferences of the land manager. It may also change over time in response to market conditions. Fodder production, such as lucerne hay, is treated as a crop as there is no harvesting by stock.

At the tertiary level it is suggested that classes be based on commodities / commodity groups that relate to ABS level 2 agricultural commodity categories (see part J ABS agricultural commodity levels).

3.3.1 Cereals
3.3.2 Beverage & spice crops
3.3.3 Hay & silage
3.3.4 Oil seeds
3.3.5 Sugar
3.3.6 Cotton
3.3.7 Tobacco
3.3.8 Legumes

3.4 Perennial horticulture Crop plants living for more than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control. Suggested tertiary classes are based on the ABS commodities Level 2 categories that relate to horticulture (see part J, ABS agricultural commodity levels).

3.4.1 Tree fruits
3.4.2 Oleaginous fruits
3.4.3 Tree nuts
3.4.4 Vine fruits
3.4.5 Shrub nuts fruits & berries
3.4.6 Flowers & bulbs
3.4.7 Vegetables & herbs

3.5 Seasonal horticulture Crop plants living for less than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control. Suggested tertiary classes are based on the ABS commodities Level 2 agricultural commodity categories that relate to horticulture (see part J ABS agricultural commodity levels).

3.5.1 Fruits
3.5.2 Nuts
3.5.3 Flowers & bulbs
3.5.4 Vegetables & herbs

(iv) PRODUCTION FROM IRRIGATED AGRICULTURE AND PLANTATIONS

This class includes agricultural land uses where water is applied to promote additional growth over normally dry periods, depending on the season, water availability and commodity prices. This includes land uses that receive only one or two irrigations per year, through to those uses that rely on irrigation for much of the growing season. Baxter and Russell (1994) argue that the degree of intervention involved in irrigation and its potential impacts on hydrology and geohydrology are sufficient to warrant creation of this primary class.

4.1 Irrigated plantation forestry Land on which irrigated plantations of trees or shrubs have been established for production or environmental and resource protection purposes. This includes farm forestry.

4.1.1 Irrigated hardwood production - managed for hardwood sawlogs or pulpwood
4.1.2 Irrigated softwood production - managed for softwood sawlogs or pulpwood
4.1.3 Irrigated other forest production - managed for non-sawlog/pulpwood production, including oil, wildflowers, fire-wood and fence posts
4.1.4 Irrigated environmental - environmental and indirect production uses (eg prevention of land degradation, wind-breaks, shade and shelter)

4.2 Irrigated modified pastures Irrigated pasture production, both annual and perennial, based on a significant degree of modification or replacement of the initial native vegetation. This class may include land in a rotation system that at other times may be under cropping. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping/pasture rotation regimes are treated as land management practices.

4.2.1 Irrigated woody fodder plants Irrigated woody plants used primarily for the purpose of providing forage for livestock grazing.
4.2.2 Irrigated legumes
4.2.3 Irrigated legume/grass mixtures
4.2.4 Irrigated sown grasses

4.3 Irrigated cropping Land under irrigated cropping. This class may include land in a rotation system that at other times may be under pasture. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping/pasture rotation regimes are treated as land management practice.

4.3.1 Irrigated cereals
4.3.2 Irrigated beverage & spice crops
4.3.3 Irrigated hay & silage
4.3.4 Irrigated oil seeds
4.3.5 Irrigated sugar
4.3.6 Irrigated cotton
4.3.7 Irrigated tobacco
4.3.8 Irrigated legumes

4.4 Irrigated perennial horticulture Irrigated crop plants living for more than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control.

4.4.1 Irrigated tree fruits
4.4.2 Irrigated oleaginous fruits
4.4.3 Irrigated tree nuts
4.4.4 Irrigated vine fruits
4.4.5 Irrigated shrub nuts fruits & berries
4.4.6 Irrigated flowers & bulbs
4.4.7 Irrigated vegetables & herbs

4.5 Irrigated seasonal horticulture Irrigated crop plants living for less than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control.

4.5.1 Irrigated fruits
4.5.2 Irrigated nuts
4.5.3 Irrigated flowers & bulbs
4.5.4 Irrigated vegetables & herbs

(v) INTENSIVE USES

Land uses involving high levels of interference with natural processes, generally in association with closer settlement. The level of intervention may be sufficiently high as to completely remodel the natural landscape — the vegetation, surface and groundwater systems and the land surface.

5.1 Intensive horticulture Intensive forms of plant production.

5.1.1 Shadehouses
5.1.2 Glasshouses
5.1.3 Glasshouses (hydroponic)

5.2 Intensive animal production Intensive forms of animal production. Agricultural production facilities such as feedlots, piggeries etc may be included as tertiary classes.

5.2.1 Dairy
5.2.2 Cattle

5.2.3 **Sheep**
5.2.4 **Poultry**
5.2.5 **Pigs**
5.2.6 **Aquaculture**

5.3 Manufacturing and industrial Factories, workshops, foundries, construction sites etc. This includes the processing of primary produce eg sawmills, pulp mills, abattoirs, etc.

5.4 Residential

5.4.1 Urban residential houses, flats, hotels, etc
5.4.2 Rural residential Characterised by agriculture in a peri-urban setting, where agriculture does not provide the primary source of income.

5.5 Services Land allocated to the provision of commercial or public services resulting in substantial interference to the natural environment. Where services are provided land that retains natural cover an appropriate classification under (i) Conservation and Natural Environments should be applied (eg 1.1.7; 1.3).

5.5.1 Commercial services Shops, markets, financial services, etc
5.5.2 Public services Education, community services, etc
5.5.3 Recreation and culture Parks, sports grounds, camping grounds, swimming pools, museums, places of worship, etc
5.5.4 Defence facilities Defence research and development establishments, testing areas, firing ranges, etc. Defence lands of significant area, retaining natural cover should be allocated to 1.3.1
5.5.5 Research facilities government and non-government research and development areas

5.6 Utilities

5.6.1 Electricity generation/transmission Coal-fired, gas-fired, solar-powered, wind-powered or hydroelectric power stations, sub-stations, powerlines, etc
5.6.2 Gas treatment, storage and transmission Facilities associated with gas production and supply

5.7 Transport and communication

5.7.1 Airports/aerodromes
5.7.2 Roads
5.7.3 Railways
5.7.4 Ports and water transport
5.7.5 Navigation and communication radar stations, beacons, etc

5.8 Mining

5.8.1 Mines
5.8.2 Quarries
5.8.3 Tailings Tailings areas and other previously mined areas under rehabilitation are included in 1.3.4

5.9 Waste treatment and disposal Waste material and disposal facilities associated with industrial, urban and agricultural activities.

5.9.1 Stormwater
5.9.2 Landfill Disposal of solid inert wastes (but not including over-burden)
5.9.3 Solid garbage Disposal of wastes including waste from processing plants
5.9.4 Incinerators
5.9.5 Sewage

(vi) WATER

Water features are regarded as essential to the classification because of their importance for natural resources management and as points of reference in the landscape. The inclusion of water is, however, complicated as it is normally classified as a land cover type. At the secondary level the classification identifies water features, both natural and artificial. Tertiary classes relate water features to intensity of use.

Because water is a land cover rather than a land use, water classes may not be mutually-exclusive with other land use classes at particular levels in the classification. Generally, water classes should take precedence so that, for instance, a lake in a conservation reserve will be classed as Lake (6.1) or Lake - conservation (6.1.1) rather than Nature conservation (1.1). Water features to which a conservation tertiary class applies may be attributed using multiple use attribution procedures (see part G for technical details).

6.1 Lake

6.1.1 Lake - conservation Feature relates to uses included in 1. Conservation and Natural Environments.
6.1.2 Lake - production Feature relates to uses included in 2. Production from Relatively Natural Environments.
6.1.3 Lake - intensive use Feature relates to uses included in 5. Intensive Uses.

6.2 Reservoir or dam

6.2.1 Water storage and treatment
6.2.2 Reservoir - intensive use Feature relates to uses in 5. Intensive Uses.
6.2.3 Evaporation basin Disposal of irrigation drainage waters.
6.2.4 Effluent pond

6.3 River

6.3.1 River - conservation Feature relates to uses in 1. Conservation and Natural Environments.
6.3.2 River - production Feature relates to uses in 2. Production from Relatively Natural Environments.
6.3.3 River - intensive use Feature relates to uses in 5. Intensive Uses.

6.4 Channel/aqueduct

6.4.1 Supply channel/aqueduct
6.4.2 Drainage channel/aqueduct

6.5 Marsh/wetland

6.5.1, Marsh/wetland - conservation Feature relates to uses in 1. Conservation and Natural Environments.
6.5.2, Marsh/wetland - production Feature relates to uses in 2. Production from Relatively Natural Environments.
6.5.3, Marsh/wetland - intensive use Feature relates to uses in 5. Intensive Uses.

6.6 Estuary/coastal waters

6.6.1 Estuary/coastal waters - conservation Feature relates to uses in 1. Conservation and Natural Environments.
6.6.2 Estuary/coastal waters - production Feature relates to uses in 2. Production from Relatively Natural Environments.
6.6.3 Estuary/coastal waters - intensive use Feature relates to uses in 5. Intensive Uses.

(vii) COMPARISON WITH OTHER AUSTRALIAN LAND USE CLASSIFICATIONS

In addition to the ALUM Classification, other land use classifications presently in use in Australia are the Western Australian Standard Land Use Classification (WASLUC) and the Australian and New Zealand Land Use Classification (ANZLUC). Both the WASLUC and ANZLUC systems are hierarchical, with nine primary classes of land use (Table 1).

Table 1
Primary Levels in the ALUM, WASLUC and ANZLUC Land Use Classification Systems

ALUM	**WASLUC**	**ANZLUC**
1 Conservation and natural environments	1 Housing	1000 Accommodation
2 Production from relatively natural environments	2 Manufacturing	2000 Manufacturing
3 Production from dryland agriculture and plantations	3 Fabricated metals manufacturing	3000 Commerce
4 Production from irrigated agriculture and plantations	4 Transportation	4000 Services
5 Intensive uses	5 Trade and industries	5000 Agriculture, Forestry and Aquaculture
6 Water	6 Commercial land use	6000 Mining or Extractive Indust
	7 Cultural and recreational uses	7000 Protected and Recreationa
	8 Agriculture	8000 Transport, Storage, Utilitie Communication
	9 Conservation and unused land	9000 Land not elsewhere classified

The strength of the WASLUC and ANZLUC classifications is in their ability to discriminate intensive uses, especially those associated with commercial and industrial uses. The WASLUC and ANZLUC classifications comprise 1,122 and more than 1,400 classes respectively, with emphasis on commercial and industrial uses rather than rural and conservation land uses. For the 71 classes that discriminate dryland and irrigated agriculture at the tertiary level in the ALUM classification, there are 40 matching WASLUC and 64 ANZLUC classes. For the 19 tertiary ALUM classes describing uses associated with conservation and natural environments there are five WASLUC and 11 ANZLUC classes.

D. ALUM Classification v5 - summary

The minimum expected level of attribution relates to land use mapping programs currently coordinated through BRS using the ALUM Classification (v5) as indicated below.

1 Conservation and Natural Environments

1.1.0 Nature conservation
- 1.1.1 Strict nature reserves
- 1.1.2 Wilderness area
- 1.1.3 National park
- 1.1.4 Natural feature protection
- 1.1.5 Habitat/species management area
- 1.1.6 Protected landscape
- 1.1.7 Other conserved area

1.2.0 Managed resource protection
- 1.2.1 Biodiversity
- 1.2.2 Surface water supply
- 1.2.3 Groundwater
- 1.2.4 Landscape
- 1.2.5 Traditional indigenous uses

1.3.0 Other minimal use
- 1.3.1 Defence
- 1.3.2 Stock route
- 1.3.3 Remnant native cover
- 1.3.4 Rehabilitation

2 Production from Relatively Natural Environments

2.1.0 Grazing natural vegetation

2.2.0 Production forestry
- 2.2.1 Wood production
- 2.2.2 Other forest production

3 Production from Dryland Agriculture and Plantations

3.1.0 Plantation forestry
- 3.1.1 Hardwood production
- 3.1.2 Softwood production
- 3.1.3 Other forest production
- 3.1.4 Environmental

3.2.0 Grazing modified pastures
- 3.2.1 Native/exotic pasture mosaic
- 3.2.2 Woody fodder plants
- 3.2.3 Pasture legumes
- 3.2.4 Pasture legume/grass mixtures
- 3.2.5 Sown grasses

3.3.0 Cropping
- 3.3.1 Cereals
- 3.3.2 Beverage & spice crops
- 3.3.3 Hay & silage
- 3.3.4 Oil seeds
- 3.3.5 Sugar
- 3.3.6 Cotton
- 3.3.7 Tobacco
- 3.3.8 Legumes

3.4.0 Perennial horticulture
- 3.4.1 Tree fruits
- 3.4.2 Oleaginous fruits
- 3.4.3 Tree nuts
- 3.4.4 Vine fruits
- 3.4.5 Shrub nuts fruits & berries
- 3.4.6 Flowers & bulbs
- 3.4.7 Vegetables & herbs

3.5.0 Seasonal horticulture
- 3.5.1 Fruits
- 3.5.2 Nuts
- 3.5.3 Flowers & bulbs
- 3.5.4 Vegetables & herbs

4 Production from Irrigated Agriculture and Plantations

4.1.0 Irrigated plantation forestry
- 4.1.1 Irrigated hardwood production
- 4.1.2 Irrigated softwood production
- 4.1.3 Irrigated other forest production
- 4.1.4 Irrigated environmental

4.2.0 Irrigated modified pastures
- 4.2.1 Irrigated woody fodder plants
- 4.2.2 Irrigated pasture legumes
- 4.2.3 Irrigated legume/grass mixtures
- 4.2.4 Irrigated sown grasses

4.3.0 Irrigated cropping
- 4.3.1 Irrigated cereals
- 4.3.2 Irrigated beverage & spice crops
- 4.3.3 Irrigated hay & silage
- 4.3.4 Irrigated oil seeds
- 4.3.5 Irrigated sugar
- 4.3.6 Irrigated cotton
- 4.3.7 Irrigated tobacco
- 4.3.8 Irrigated legumes

4.4.0 Irrigated perennial horticulture
- 4.4.1 Irrigated tree fruits
- 4.4.2 Irrigated oleaginous fruits
- 4.4.3 Irrigated tree nuts
- 4.4.4 Irrigated vine fruits
- 4.4.5 Irrigated shrub nuts fruits & berries
- 4.4.6 Irrigated flowers & bulbs
- 4.4.7 Irrigated vegetables & herbs

4.5.0 Irrigated seasonal horticulture
- 4.5.1 Irrigated fruits
- 4.5.2 Irrigated nuts
- 4.5.3 Irrigated flowers & bulbs
- 4.5.4 Irrigated vegetables & herbs

5 Intensive Uses

5.1.0 Intensive horticulture
- 5.1.1 Shadehouses
- 5.1.2 Glasshouses
- 5.1.3 Glasshouses (hydroponic)

5.2.0 Intensive animal production
- 5.2.1 Dairy
- 5.2.2 Cattle
- 5.2.3 Sheep
- 5.2.4 Poultry
- 5.2.5 Pigs
- 5.2.6 Aquaculture

5.3.0 Manufacturing and industrial

5.4.0 Residential
- 5.4.1 Urban residential
- 5.4.2 Rural residential

5.5.0 Services
- 5.5.1 Commercial services
- 5.5.2 Public services
- 5.5.3 Recreation and culture
- 5.5.4 Defence facilities
- 5.5.5 Research facilities

5.6.0 Utilities
- 5.6.1 Electricity generation/transmission
- 5.6.2 Gas treatment, storage and transmission

5.7.0 Transport and communication
- 5.7.1 Airports/aerodromes
- 5.7.2 Roads
- 5.7.3 Railways
- 5.7.4 Ports and water transport
- 5.7.5 Navigation and communication

5.8.0 Mining
- 5.8.1 Mines
- 5.8.2 Quarries
- 5.8.3 Tailings

5.9.0 Waste treatment and disposal
- 5.9.1 Stormwater
- 5.9.2 Landfill
- 5.9.3 Solid garbage
- 5.9.4 Incinerators
- 5.9.5 Sewage

6 Water

6.1.0 Lake
- 6.1.1 Lake - conservation
- 6.1.2 Lake - production
- 6.1.3 Lake - intensive use

6.2.0 Reservoir/dam
- 6.2.1 Water storage and treatment
- 6.2.2 Reservoir - intensive use
- 6.2.3 Evaporation basin
- 6.2.4 Effluent pond

6.3.0 River
- 6.3.1 River - conservation
- 6.3.2 River - production
- 6.3.3 River - intensive use

6.4.0 Channel/aqueduct
- 6.4.1 Supply channel/aqueduct
- 6.4.2 Drainage channel/aqueduct

6.5.0 Marsh/wetland
- 6.5.1 Marsh/wetland - conservation
- 6.5.2 Marsh/wetland - production
- 6.5.3 Marsh/wetland - intensive use

6.6.0 Estuary/coastal waters
- 6.6.1 Estuary/coastal waters - conservation
- 6.6.2 Estuary/coastal waters - production
- 6.6.3 Estuary/coastal waters - intensive use

minimum level of attribution

Appendix 2: 'Environ' categories selected from Queensland NVIS data to create riparian coverage's

Qld NVIS re v5 –Riparian categories

1. Occurs on alluvial plains with light sandy loam soil
2. Occurs on alluvial plains
3. Occurs on recent alluvium
4. Alluvium
5. Associated with coastal swamps
6. Associated with riverine levees and floodplains
7. Associated with streams, on low sandstone plateaus
8. Associated with swamps and dune swales
9. Creek beds
10. Drainage depressions in upland situations
11. Drainage depressions of coastal floodplains
12. Flood deposited gravel and sand banks in the beds of major streams
13. Fringes major streams and creeks
14. Fringing forests of larger streams
15. Groundwater seepage zones on swamp fringes
16. Lower slopes of sand ridges and in drainage depressions
17. Moist and dry lowlands on alluvium, predominantly riverine levees
18. Occur on alluvial plains
19. Occurs along sandy or gravely drainage lines, channels and inter-channel areas of north-western river systems. Soils vary from very deep, coarse sands to silty clays, sandy clay loams and gravely loams
20. Occurs along sandy or gravely drainage lines, channels and inter-channel flats of larger drainage lines. Also occurs as low woodland in drainage lines of some residuals. Soils variable and include deep, loose coarse sands, silty clays, sandy clay loams
21. Occurs along stream channels mostly in upper parts of catchments of eastern flowing streams
22. Occurs along watercourses
23. Occurs in alluvial depressions on lower slopes and valley floors
24. Occurs in channels of large streams
25. Occurs in closed depressions on Tertiary sand plain or ferricrete with grey clay soils
26. Occurs in depressions on weathered sandstone plateaus

27. Occurs in drainage lines on seepage from adjoining sandsheet
28. Occurs in drainage swamps, which generally remain flooded in the wet season for many months
29. Occurs in ephemeral lakes and lagoons on alluvial plains and depressions that progressively dry out in dry season
30. Occurs in lagoons on Quaternary alluvial plains; grey clays, some gleyed podzolics; in deep open water
31. Occurs in lagoons on deep weathered Mesozoic plateau surfaces; yellow earths and solodised solonetz
32. Occurs in larger river channels
33. Occurs in longitudinal drainage depressions
34. Occurs in narrow bands along longitudinal drainage lines
35. Occurs in permanent lakes and lagoons frequently with fringing woodlands
36. Occurs in rounded shallow lagoons which are seasonally flooded; yellow podzolic soils
37. Occurs in shallow gully lines and drainage depressions in rolling granite or rhyolite hills
38. Occurs in shallow inundated depressions of clay, silt and nodular ferricrete
39. Occurs in sinkholes and drainage depressions
40. Occurs in swamps
41. Occurs o the Mitchell River floodplain
42. Occurs on Quaternary alluvial plains; cracking clay soils
43. Occurs on Tertiary and Quaternary alluvial plains; earths and solodised solonetz soils
44. Occurs on abandoned levees, and levees associated with current major watercourses; fine sands, alluvial soils and red earths
46. Occurs on alluvia adjacent to drainage lines. Soils generally grey or brown, heavy clays
47. Occurs on alluvia and drainage lines in undulating clay plains dominated by Astrebla spp. tussock grasslands. Soils are predominately deep, red, brown or grey, cracking clays
48. Occurs on alluvia immediately above drainage lines. Soils moderately deep to deep, red and brown clays. The surface is usually crusting. Soils are neutral to alkaline and gypsum occurs at depth
49. Occurs on alluvia on major watercourses
50. Occurs on alluvial deposits along major watercourses; alluvial soils
51. Occurs on alluvial grey clay deposits derived from basalt soils (as compared with 9.3.26)
52. Occurs on alluvial levees and plains with deep alluvial soils

53. Occurs on alluvial plains adjacent to major watercourses, on dark clay soils washed down from basalt areas

54. Occurs on alluvial plains with drainages

55. Occurs on alluvial plains, levees and prior stream traces on floodplains; fine sandy brown soils and sandy yellow earths

56. Occurs on alluvial plains, terraces and levees. Soils are generally sandy alluvium

57. Occurs on alluvial plains

58. Occurs on alluvial terraces and levees on sand, silt and clay

59. Occurs on alluvial terraces, levees, frontages with sand, silt and clay soils

60. Occurs on alluvial terraces

61. Occurs on alluvium associated with major watercourses; gravely calcareous clays, some red-brown earths

62. Occurs on alluvium derived from metamorphics

63. Occurs on alluvium

64. Occurs on artesian springs

65. Occurs on back plains of alluvial plains

66. Occurs on banks of small creeks with sandy soil

67. Occurs on breakaways on edge of alluvial terraces and mudstones

68. Occurs on broad drainage depressions

69. Occurs on broad shallow drainage areas on undulating plains

70. Occurs on channel benches, levees and terraces on deep loamy sands or sandy clay loams (often with loose surface gravel)

71. Occurs on channel deposits in minor watercourses

72. Occurs on channelled and flooded backplains on Tertiary and Quaternary alluvium, usually formed between the levee of a major watercourse and adjacent higher ground; grey cracking clays

73. Occurs on channels and inner levees on younger Quaternary alluvium; alluvial sands and loams

74. Occurs on channels, levees and plains associated with recent watercourses; alluvial soils, mainly sands and earths

75. Occurs on clay plain with partial saline influence

76. Occurs on clay plains on older alluvial fan deposits

77. Occurs on closed depressions and shallow valley floors on Tertiary and Quaternary alluvium, seasonally flooded; soloths, solodised solonetz and leached grey and brown massive earths

78. Occurs on closed depressions and shallow valley floors on Tertiary and Quaternary alluvium, seasonally flooded; soloths, solodised solonetz and leached grey and brown massive earths

79. Occurs on closed depressions on sandy Tertiary plains; cracking clays, with solodised solonetz in centres of larger depressions

80. Occurs on creek banks and drainage lines and smaller creek flats in the basalt shields. Includes adjacent flats

81. Occurs on creeks and watercourses

82. Occurs on creeks, drainages, plains

83. Occurs on depressions and floodplains on Quaternary and Tertiary alluvial plains; calcareous cracking clays

84. Occurs on drainage areas and floodplains

85. Occurs on drainage swamps in dunefields

86. Occurs on elevated alluvial terraces in river channels

87. Occurs on ephemeral swamps with silt, clay and nodular ferricrete bases

88. Occurs on erosional and alluvial plains

89. Occurs on flat alluvial plains of major rivers with minor occurrences on interchannel alluvia and in well drained clay pans. Soils very deep, grey and brown cracking clays. Flooding frequency variable depending on position in landscape

90. Occurs on flat alluvial plains

91. Occurs on floodplains and drainage and swampy areas

92. Occurs on floodplains

93. Occurs on gentle slopes fringing depressions on Tertiary surfaces; solodised solonetz soils. Fringes seasonal wetlands

94. Occurs on gently sloping terrain adjacent to creeks

95. Occurs on head waters of drainage lines and shallow drainage depressions in Tertiary sandstone plateaus

96. Occurs on heavy clay alluvium

97. Occurs on higher level clay plain not influenced by tides

98. Occurs on levees and banks of intermediate and larger drainage channels and associated alluvial plains. Soils very deep, brown or grey clays with sand and silt bands common in profile

99. Occurs on levees and some floodplains of larger watercourses; alluvial soils and calcareous cracking clays

100. Occurs on levees associated with streams

101. Occurs on levees, terraces and banks of larger rivers and on flat to very gentle slopes associated with drainage lines

102. Occurs on levees

103. Occurs on low - elevated plains seasonally inundated by fresh water or rarely by saline waters; solonetzic soils

104. Occurs on low-level terraces and levees on younger Quaternary alluvium of upper tributary watercourses; alluvial sands and loams

105. Occurs on low-lying plains

106. Occurs on major and minor channels; fine alluvial soils, minor calcareous clays

107. Occurs on major channels; coarse alluvial soils

108. Occurs on naturally eroding drainage areas associated with streamlines or at edges of saltpans

109. Occurs on old levees on the Mitchell River floodplain

110. Occurs on plains older alluvial fan and overbank deposits

111. Occurs on plains on older Quaternary alluvial fan and overbank deposits

112. Occurs on plains on older alluvial fan and overbank deposits

113. Occurs on recent alluvial terraces of larger watercourses and in channel deposits of ephemeral streams

114. Occurs on recent levees and channel deposits of major watercourses and larger tributaries

115. Occurs on recent levees and channel deposits of medium and smaller tributaries which are dry for most of the year; alluvial soils

116. Occurs on sandy alluvial terraces (eastern)

117. Occurs on sandy levees and ridges

118. Occurs on seasonally flooded marine plains, in areas inundated with 15-40 cm of water in the wet season

119. Occurs on seasonally inundated depressions on marine plains

120. Occurs on shallow braided channels on alluvia above major drainage lines. Very deep, crusted, red, brown and grey cracking clays with minor crusted non-cracking red clays. Gravel may occur in the profile and gypsum usually occurs at depth. Textures range

121. Occurs on shallow drainage depressions on deep weathered Mesozoic plateau surfaces; solodised solonetz soils

122. Occurs on shallow drainages on plains

123. Occurs on smaller drainage lines, sometimes braided, within the Astrebla spp. undulating plains. Soils deep, grey and brown cracking clays. Sand and silt bands may occur in profile

124. Occurs on stream and channel banks,

125. Occurs on stream and channel banks

126. Occurs on stream banks and channels in areas of higher rainfall in the central east of the bioregion (subregion 6)

127. Occurs on stream banks and channels on western-flowing rivers draining the Hodgkinson Basin metamorphics (subregion 3)

128. Occurs on stream channels flowing east and west and on flood plains

129. Occurs on streamlines, swamps and alluvial terraces
130. Occurs on swamps
131. Occurs on swamps and occasionally along creek lines on basalt geologies
132. Occurs on swamps, lakes and billabongs on alluvial plains
133. Occurs on terraces and floodplains on Quaternary alluvium; alluvial soils, some earths and deep yellow podzolics
134. Occurs on the fringes of river channels, with sandy and gravely soils
135. Occurs on undulating plains and colluvial fans
136. Occurs surrounding permanent waterholes in major rivers. Soils very deep, brown or grey clays with sand and silt bands common in profile
137. Perched drainage areas on peats
138. Permanently to semi-permanently inundated peat swamps of alluvial plains
139. Permanently wet swamps of drainage lines in upland situations
140. Plains on Tertiary and Quaternary alluvial deposits; partly flooded; leached grey and brown massive earths, soloths, solodised solonetz and cracking clay soils
141. Poorly drained alluvium, mostly on the coastal plains
142. Poorly drained soils of coastal lowlands
143. River beds without permanent water, generally sandy
144. River flood plains
145. Rivers and creeks
146. Rivers and water holes with permanent water
147. Rock cobble and gravel deposits of the active flood path of major streams
148. Rubble terraces of streams
149. Sandy river beds
150. Semi-permanent swamps of coastal lowlands
151. Stream levees and prior streams on well-drained sandy clay loam alluvial soils
152. Swampy drainage lines and swamp fringes in upland situations
153. Swampy soils on the headwater valleys of permanent streams and rivers
154. Very wet and wet lowlands on poorly drained peaty humic gley soils where the water table is near or above the ground for most of the year
155. Very wet lowlands and lower foothills on humic gley alluvial soils with seasonally impeded drainage derived from metamorphic and granitic parent material
156. Widely distributed on alluvial and erosional plains and in drainage depressions

Qld NVIS revised–Riparian categories

1. Occurs on alluvium and associated flats on LZ 5.
2. Occurs on depositional plains

3. Occurs on drainage lines and alluvial plains

Qld NVIS cwqsw–Riparian categories

1. Alluvial plains with frequent scalds.
2. Alluvia and drainage lines in western regions, undulating clay pans
3. Drainage lines, channels and inter-channel areas of north-western river systems
4. Flat, occasionally flooded areas adjacent to stream lines (Mt. Isa highlands)
5. Flat/gently undulating plains, adjacent to alluvia/fringing undulating downs
6. Levees and banks of major drainage channels on braided alluvial plains
7. Levees and sandplains along major streams
8. Occurs on the old alluvial flats associated with the Warrego River. Soils usually very deep, neutral to alkaline, brown alluvial cracking clays.

Qld NVIS fnq –Riparian categories

1. Occurs on alluvial plains with light sandy loam soil.
2. Occurs on alluvial plains.
3. Occurs on recent alluvium.
4. Alluvial plains with frequent scalds.
5. Adjacent streamlines. Bleached-Mottled Yellow Kandosols and Humic Aquic Podosols.
6. Alluvia and drainage lines in western regions, undulating clay pans
7. Alluvial and colluvial plains and on gently undulating plains with variable dermosols
8. Alluvial and erosional plains and drainage depressions with dermosols or kandosols
9. Alluvial and erosional plains. Yellow and Brown Dermosol, significant areas also of Brown or Grey Vertosols and Dermosolic Oxyaquic Hydrosols
10. Alluvial and flood plains on varied geology with dermosols or kandosols
11. Alluvial and flood plains. Humic Aquic or Semi-aquic Podosols, occasionally on Orthic Tenosols and Yellow Kandosols.
12. Alluvial and flood plains. Redoxic Hydrosols
13. Alluvial plains and fans with brown or yellow dermosols or kandosols
14. Alluvial plains with dermosols or kandosols
15. Alluvial plains with hydrosols, kandosols and dermosols
16. Alluvium.
17. Associated with coastal swamps
18. Associated with riverine levees and floodplains.
19. Associated with streams, on low sandstone plateaus.

20. Associated with swamps and dune swales.
21. Badly eroding drainage areas. Footslopes and pediments of sandstone ranges. Sodosolic or Dermosolic Redoxic Hydrosols.
22. Creek beds.
23. Creek margins and estuaries on unconsolidated mud (intertidal hydrosols)
24. Depositional and flood plains and in drainage depressions. Sodosolic Redoxic Hydrosols.
25. Depressions flooded in the wet season. Probably Humose or Redoxic Hydrosols enriched by organic matter.
26. Drainage depressions and lower slopes of sand ridges with kandosols and hydrosols
27. Drainage depressions and swamps with hydrosols
28. Drainage depressions and swamps, depositional plains. Humose or Melanic Orthic Redoxic Hydrosols.
29. Drainage depressions in upland situations.
30. Drainage depressions of coastal floodplains.
31. Drainage lines, channels and inter-channel areas of north-western river systems
32. Drainage lines, colluvial plains derived from metamorphic rocks. Redoxic Hydrosols.
33. Drainage swamps with hydrosols
34. Dunefields on swampy sandplains. Humic Aquic or Semi-aquic Podosols.
35. Erosional and alluvial plains and in drainage depressions. Sodosolic Redoxic Hydrosols, also on Mesotrophic Kandosols and Dermosolic Redoxic Hydrosols.
36. Erosional and alluvial plains with kandosols, dermosols or tenosols
37. Erosional and alluvial plains. Redoxic Hydrosols, with some occurrences on Mesotrophic Kandosols and Grey Sodosols.
38. Erosional plains and flood plains. Redoxic Hydrosols.
39. Flat alluvial plains. Grey Vertosols (Ug 5.24) and soils with the affinities to Yellow Kandosols and Dermosols.
40. Flat alluvial plains. Oxyaquic Hydrosols or Aquic Vertosols occurring on Quaternary alluvia.
41. Flat, occasionally flooded areas adjacent to stream lines (Mt. Isa highlands)
42. Flat/gently undulating plains, adjacent to alluvia/fringing undulating downs
43. Flood deposited gravel and sand banks in the beds of major streams.
44. Fringes major streams and creeks with tenosols or hydrodols
45. Fringes major streams and creeks.
46. Fringes streams and creeks with tenosols or hydrosols
47. Fringing forests of larger streams.
48. Groundwater seepage zones on swamp fringes.

49. In floodplains on sandy levees lining shallow drainage lines with kandosols or dermosols

50. Levees and banks of major drainage channels on braided alluvial plains

51. Levees and sandplains along major streams

52. Longitudinal drainage depressions. Sodosolic or Dermosolic Redoxic Hydrosols.

53. Lower slopes of sand ridges and in drainage depressions.

54. Moist and dry lowlands on alluvium, predominantly riverine levees.

55. Narrow floodplains and levees adjacent to streamlines with hydrosols and dermosols

56. Occur on alluvial plains.

57. Occurs along sandy or gravely drainage lines, channels and inter-channel areas of north-western river systems. Soils vary from very deep, coarse sands to silty clays, sandy clay loams and gravely loams.

58. Occurs along sandy or gravely drainage lines, channels and inter-channel flats of larger drainage lines. Also occurs as low woodland in drainage lines of some residuals. Soils variable and include deep, loose coarse sands, silty clays, sandy clay loams

59. Occurs along stream channels mostly in upper parts of catchments of eastern flowing streams.

60. Occurs along watercourses.

61. Occurs in alluvial depressions on lower slopes and valley floors.

62. Occurs in channels of large streams.

63. Occurs in closed depressions on Tertiary sand plain or ferricrete with grey clay soils.

64. Occurs in depressions on weathered sandstone plateaus.

65. Occurs in drainage lines on seepage from adjoining sandsheet.

66. Occurs in drainage swamps, which generally remain flooded in the wet season for many months.

67. Occurs in ephemeral lakes and lagoons on alluvial plains and depressions that progressively dry out in dry season.

68. Occurs in lagoons on Quaternary alluvial plains; grey clays, some gleyed podzolics; in deep open water.

69. Occurs in lagoons on deep weathered Mesozoic plateau surfaces; yellow earths and solodised solonetz.

70. Occurs in larger river channels.

71. Occurs in longitudinal drainage depressions.

72. Occurs in narrow bands along longitudinal drainage lines.

73. Occurs in permanent lakes and lagoons frequently with fringing woodlands.

74. Occurs in rounded shallow lagoons which are seasonally flooded; yellow podzolic soils.

75. Occurs in shallow gully lines and drainage depressions in rolling granite or rhyolite hills

76. Occurs in shallow inundated depressions of clay, silt and nodular ferricrete.

77. Occurs in sinkholes and drainage depressions.

78. Occurs in swamps.

79. Occurs o the Mitchell River floodplain.

80. Occurs on Quaternary alluvial plains; cracking clay soils.

81. Occurs on Tertiary and Quaternary alluvial plains; earths and solodised solonetz soils.

82. Occurs on abandoned levees, and levees associated with current major watercourses; fine sands, alluvial soils and red earths.

83. Occurs on alluvia adjacent to drainage lines. Soils generally grey or brown, heavy clays.

84. Occurs on alluvia and drainage lines in undulating clay plains dominated by Astrebla spp. tussock grasslands. Soils are predominately deep, red, brown or grey, cracking clays.

85. Occurs on alluvia immediately above drainage lines. Soils moderately deep to deep, red and brown clays. The surface is usually crusting. Soils are neutral to alkaline and gypsum occurs at depth.

86. Occurs on alluvia on major watercourses.

87. Occurs on alluvial deposits along major watercourses; alluvial soils.

88. Occurs on alluvial grey clay deposits derived from basalt soils (as compared with 9.3.26).

89. Occurs on alluvial levees and plains with deep alluvial soils.

90. Occurs on alluvial plains adjacent to major watercourses, on dark clay soils washed down from basalt areas

91. Occurs on alluvial plains with drainages.

92. Occurs on alluvial plains, levees and prior stream traces on floodplains; fine sandy brown soils and sandy yellow earths.

93. Occurs on alluvial plains, terraces and levees. Soils are generally sandy alluvium

94. Occurs on alluvial plains.

95. Occurs on alluvial terraces and levees on sand, silt and clay.

96. Occurs on alluvial terraces, levees, frontages with sand, silt and clay soils.

97. Occurs on alluvial terraces.

98. Occurs on alluvium associated with major watercourses; gravely calcareous clays, some red-brown earths.

99. Occurs on alluvium derived from metamorphics.

100. Occurs on alluvium.

101. Occurs on artesian springs.

102. Occurs on back plains of alluvial plains.

103. Occurs on banks of small creeks with sandy soil.

104. Occurs on breakaways on edge of alluvial terraces and mudstones.

105. Occurs on broad drainage depressions.

106. Occurs on broad shallow drainage areas on undulating plains.

107. Occurs on channel benches, levees and terraces on deep loamy sands or sandy clay loams (often with loose surface gravel).

108. Occurs on channel deposits in minor watercourses.

109. Occurs on channelled and flooded backplains on Tertiary and Quaternary alluvium, usually formed between the levee of a major watercourse and adjacent higher ground; grey cracking clays.

110. Occurs on channels and inner levees on younger Quaternary alluvium; alluvial sands and loams.

111. Occurs on channels, levees and plains associated with recent watercourses; alluvial soils, mainly sands and earths;

112. Occurs on clay plain with partial saline influence.

113. Occurs on clay plains on older alluvial fan deposits.

114. Occurs on closed depressions and shallow valley floors on Tertiary and Quaternary alluvium, seasonally flooded; soloths, solodised solonetz and leached grey and brown massive earths

115. Occurs on closed depressions on sandy Tertiary plains; cracking clays, with solodised solonetz in centres of larger depressions

116. Occurs on creek banks and drainage lines and smaller creek flats in the basalt shields. Includes adjacent flats.

117. Occurs on creeks and watercourses

118. Occurs on creeks, drainages, plains.

119. Occurs on depressions and floodplains on Quaternary and Tertiary alluvial plains; calcareous cracking clays.

120. Occurs on drainage areas and floodplains.

121. Occurs on drainage areas.

122. Occurs on drainage swamps in dunefields.

123. Occurs on elevated alluvial terraces in river channels.

124. Occurs on ephemeral swamps with silt, clay and nodular ferricrete bases.

125. Occurs on erosional and alluvial plains

126. Occurs on flat alluvial plains of major rivers with minor occurrences on interchannel alluvia and in well drained clay pans. Soils very deep, grey and brown cracking clays. Flooding frequency variable depending on position in landscape.

127. Occurs on flat alluvial plains.

128. Occurs on floodplains and drainage and swampy areas.

129. Occurs on floodplains.

130. Occurs on gentle slopes fringing depressions on Tertiary surfaces; solodised solonetz soils. Fringes seasonal wetlands.

131. Occurs on gently sloping terrain adjacent to creeks.

132. Occurs on head waters of drainage lines and shallow drainage depressions in Tertiary sandstone plateaus.

133. Occurs on heavy clay alluvium.

134. Occurs on higher level clay plain not influenced by tides.

135. Occurs on levees and banks of intermediate and larger drainage channels and associated alluvial plains. Soils very deep, brown or grey clays with sand and silt bands common in profile.

136. Occurs on levees and some floodplains of larger watercourses; alluvial soils and calcareous cracking clays.

137. Occurs on levees associated with streams.

138. Occurs on levees, terraces and banks of larger rivers and on flat to very gentle slopes associated with drainage lines.

139. Occurs on levees.

140. Occurs on low - elevated plains seasonally inundated by fresh water or rarely by saline waters; solonetzic soils.

141. Occurs on low-level terraces and levees on younger Quaternary alluvium of upper tributary watercourses; alluvial sands and loams.

142. Occurs on low-lying plains.

143. Occurs on major and minor channels; fine alluvial soils, minor calcareous clays.

144. Occurs on major channels; coarse alluvial soils.

145. Occurs on naturally eroding drainage areas associated with streamlines or at edges of saltpans

146. Occurs on old levees on the Mitchell River floodplain.

147. Occurs on plains older alluvial fan and overbank deposits.

148. Occurs on plains on older Quaternary alluvial fan and overbank deposits.

149. Occurs on plains on older alluvial fan and overbank deposits.

150. Occurs on recent alluvial terraces of larger watercourses and in channel deposits of ephemeral streams.

151. Occurs on recent levees and channel deposits of major watercourses and larger tributaries.

152. Occurs on recent levees and channel deposits of medium and smaller tributaries which are dry for most of the year; alluvial soils.

153. Occurs on sandy alluvial terraces (eastern).

154. Occurs on sandy levees and ridges.

155. Occurs on seasonally flooded marine plains, in areas inundated with 15-40 cm of water in the wet season

156. Occurs on seasonally inundated depressions on marine plains.

157. Occurs on shallow braided channels on alluvia above major drainage lines. Very deep, crusted, red, brown and grey cracking clays with minor crusted non-cracking red clays. Gravel may occur in the profile and gypsum usually occurs at depth. Textures range

158. Occurs on shallow drainage depressions on deep weathered Mesozoic plateau surfaces; solodised solonetz soils;

159. Occurs on shallow drainages on plains.

160. Occurs on smaller drainage lines, sometimes braided, within the Astrebla spp. undulating plains. Soils deep, grey and brown cracking clays. Sand and silt bands may occur in profile.

161. Occurs on stream and channel banks,

162. Occurs on stream and channel banks.

163. Occurs on stream banks and channels in areas of higher rainfall in the central east of the bioregion (subregion 6).

164. Occurs on stream banks and channels on western-flowing rivers draining the Hodgkinson Basin metamorphics (subregion 3)

165. Occurs on stream channels flowing east and west and on flood plains.

166. Occurs on streamlines, swamps and alluvial terraces.

167. Occurs on swamps .

168. Occurs on swamps and occasionally along creek lines on basalt geologies.

169. Occurs on swamps, lakes and billabongs on alluvial plains.

170. Occurs on terraces and floodplains on Quaternary alluvium; alluvial soils, some earths and deep yellow podzolics.

171. Occurs on the fringes of river channels, with sandy and gravely soils.

172. Occurs on the old alluvial flats associated with the Warrego River. Soils usually very deep, neutral to alkaline, brown alluvial cracking clays.

173. Occurs on undulating plains and colluvial fans.

174. Occurs surrounding permanent waterholes in major rivers. Soils very deep, brown or grey clays with sand and silt bands common in profile.

175. On sides of longitudinal drainage depressions draining gently sloping plains with hyrodols and some kandosols

176. Perched drainage areas on peats.

177. Permanently to semi-permanently inundated peat swamps of alluvial plains.

178. Permanently wet swamps of drainage lines in upland situations.

179. Plains on Tertiary and Quaternary alluvial deposits; partly flooded; leached grey and brown massive earths, soloths, solodised solonetz and cracking clay soils;

180. Poorly drained alluvium, mostly on the coastal plains.

181. Poorly drained soils of coastal lowlands.

182. Quaternary residual sand and washouts, also drainage areas. Humic Aquic Podosols or Orthic Tenosols, probable occurrences on Yellow Kandosols.

183. River beds without permanent water, generally sandy

184. River flood plains.

185. Rivers and creeks.

186. Rivers and water holes with permanent water

187. Rock cobble and gravel deposits of the active flood path of major streams.

188. Rubble terraces of streams.

189. Sandy river beds.

190. Seasonally flooded saline marine plains / basins of swamps and sinkholes. Yellow Dermosols (Dy 3.11), Aquic Vertosols (Ug 5.24) and Supratidal Hydrosols (Dy 1.1). Mapped as occurring on Aquic or Grey Vertosols and Intertidal Hydrosols.

191. Seasonally inundated depressions on marine and alluvial plains. Grey Vertosols, Oxyaquic or Redoxic Hydrosols.

192. Semi-permanent swamps of coastal lowlands.

193. Stream banks and terraces with sandy alluviums

194. Stream levees and prior streams on well-drained sandy clay loam alluvial soils.

195. Stream levees on flood plains with hydrosols or kandosols

196. Streamlines, swamps and alluvial terraces on stream margins with redoxic hydrosols

197. Swampy drainage lines and swamp fringes in upland situations.

198. Swampy soils on the headwater valleys of permanent streams and rivers.

199. Very wet and wet lowlands on poorly drained peaty humic gley soils where the water table is near or above the ground for most of the year.

200. Very wet lowlands and lower foothills on humic gley alluvial soils with seasonally impeded drainage derived from metamorphic and granitic parent material.

201. Waterlogged situations and drainage swamps in dune swales. Predominantly parapanic or fragic humic aquic or semi-aquic podosols.

202. Widely distributed on alluvial and erosional plains and in drainage depressions.

Appendix 3: Summary of sources of uncertainty for selected pressures/threats and habitats and qualitative ranking of uncertainty level at the Northern Tropical Rivers scale

Habitat	Uncertainty in the parameter	Level of uncertainty (Low, Medium, High)
Waterways	Not all waterways have been accurately mapped in the dataset used	Medium
	Alterations in hydrology will result in different effects depending on the characteristics of the waterway	
	Regulated waterways and impoundment are not accounted for	
Riparian Habitat	Type of riparian habitat is not accounted for (some riparian habitats are more resilient to disturbance than others)	High (WA and Qld) Low (NT)
	Size of habitat is important in determining effects	
	Change in vegetation structure due to disturbance is not explicit which can determine effects	
	Under-estimation of the amount and location of riparian habitat in Western Australian risk regions, and over-estimation in Queensland risk regions	
Wetlands	Different wetland types respond differently to disturbance (some may have a higher degree of resilience- e.g. saline coastal flats)	Medium
	Smaller patches of wetland may be more susceptible to disturbance than larger patches	
	Some fauna species can adapt to habitat degradation (e.g. waterbirds that can migrate to other habitat if available)	
Sea level rise	Does not take into account where wetlands < 1m exist where there is tidal influence greater than 70 km inland.	Medium
	Reliant on the accuracy of the DEM	
	Does not take into account the impact of extreme venets such as storm surge.	
Transport & communications	Does not account for type of activity (some habitats will have a neglible exposure or effect)	High
	All activities in all risk regions are modelled the same	
Weeds	Does not include *Mimosa pigra* and *Urochloa mutica*	High
	Based on expert opinion of occurrence and density	
	Data is eight years old and some species have spread and increased their density in that time	