Chapter 1

Introduction

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1.1 Background and context

Australia's tropical river systems are unique and form one of the last great river networks in less-impacted condition in the world today. Together, they constitute an internationally significant asset (Australian Tropical Rivers Group 2004). However, increasing pressure on water supply and river systems in southern Australia is driving strong interest in the potential for greater use for agriculture of the perceived abundant water resources in northern Australia (Gehrke et al 2004). The existence of substantial mineral and energy resources in this region will further add to development pressures over the next 10-20 years.

To achieve sustainable development and growth in northern Australia, utilisation of the water resources of our tropical rivers will need to be balanced with providing appropriate protection of the riverine and wetland ecosystems, and the many benefits they provide to society. For this vision of sustainable development to be effectively realised, a better understanding of the aquatic ecosystems is required. However, these ecosystems have yet to be studied in a systematic manner. Across the Australian tropics it is generally only those catchments with existing mining, urban, or intensive agricultural development that have specific information available on ecology, biology, geomorphology, hydrology and management requirements. Consequently, the available information is fragmented and insufficient for addressing the management needs of the future (Land & Water Australia 2004).

Sustainable management of Australia's tropical rivers and wetlands will require an integrated information base for assessment of ecological character, status and change, and the development of policy, especially for environmental flows and potentially competing uses of water. To progress towards this goal the project "*Australia's tropical rivers – an integrated data assessment and analysis*", more commonly referred to as the *Tropical Rivers Inventory and Assessment Project*, or TRIAP, was initiated in 2004. The overarching aim of the TRIAP was to establish an integrated information base and framework, built on consultation with stakeholders and analysis of existing information, for assessing status and change of Australia's tropical rivers (ie. river basins within the Timor Sea and Gulf of Carpentaria drainage divisions; referred to herein as the ***Northern Tropical Rivers***).

Funded by the Natural Heritage Trust II and Land & Water Australia, and building on the information base compiled by NGIS (2004), the TRIAP consists of three Sub-projects:

1. Inventory of the biological, chemical and physical features of aquatic ecosystems;
2. Assessment of the major pressures on aquatic ecosystems; and
3. Development of a framework for the analysis of ecosystem services provided by aquatic ecosystems.

The outcomes of Sub-projects 1 and 3 have been reported separately by Lukacs & Finlayson (2008) and De Groot et al (2008), respectively. This report presents the outcomes of Sub-project 2.

The conceptual basis for the TRIAP was provided by an integrated framework for wetland inventory, assessment and monitoring (WIAM; Figure 1.1), the most recent version of which was published by Finlayson et al (2005). The WIAM model, which has been formally adopted and promoted by the Ramsar Wetlands Convention, emphasises that although inventory, assessment and monitoring are discrete components, they are inter-connected and can operate at very different scales. For a given investigation, however, scale should be common across all three components to avoid information collected at one scale being used to make decisions or choices at another scale (Finlayson et al 2005). Thus, the multi-scalar nature of the WIAM framework is well-suited for analyses across an area as vast and diverse as northern Australia.

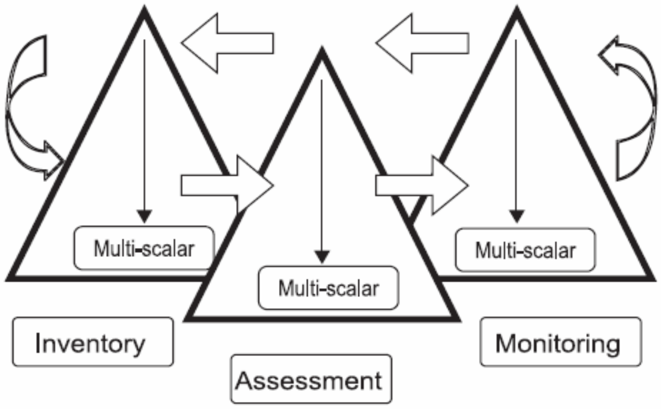

Figure 1.1 Framework for integrated wetland inventory, assessment and monitoring (WIAM). Modified from Finlayson et al (2005).

Although the existing biophysical information base for the Northern Tropical Rivers is known to be limited (relative to the size of the region), agricultural and mining development is already occurring and future opportunities are being actively and strategically explored on a northern Australian scale (Commonwealth Government of Australia 2007). Consequently, there is a need to assess the risks to aquatic ecosystems now, based on the best available information, rather than waiting until additional biophysical, socio-cultural nd economic data have been collected. Moreover, it is an appropriate time to be exploring methods and tools for assessing risk of current development and future development scenarios, including dealing with the uncertainties associated with limited data and knowledge.

This study, *Ecological risk assessments for Australia's Northern Tropical Rivers*, builds on recent efforts to develop ecological risk assessment approaches for Australia (eg. Hart 2004; Hart et al 2005), and applies some of these at various spatial scales across the Northern Tropical Rivers study area, thus providing some initial risk estimates for key pressures and threats to specific ecological assets.

1.2 Study area

The geographic area considered in this project was the Northern Tropical Rivers study area (Figure 1.2), as defined by NGIS (2004) and adopted by Land & Water Australia as the geographic coverage for its Tropical Rivers Program (Land & Water Australia 2005). The region's key features are more thoroughly described in TRIAP Sub-project 1 (Lukacs & Finlayson 2008). The Northern Tropical Rivers study area encompasses 51 river drainage basins over an area of approximately 1.2 million km^2, from Broome in Western Australia (Cape Leveque Coast catchment) to the northern tip of Cape York in Queensland (Jardine River catchment).

As with Lukacs & Finlayson (2008), the study addressed three focus catchments in much more detail, these being the Fitzroy River in WA, the Daly River in NT and the Flinders River in Qld (Figure 1.2). The focus catchments were selected based on the ecological and economic importance of the catchments within their jurisdiction, as ascertained from stakeholder consultations. Details of the scope and objectives of the project are provided in Section 1.4. First, however, it is necessary to introduce the process of ecological risk assessment.

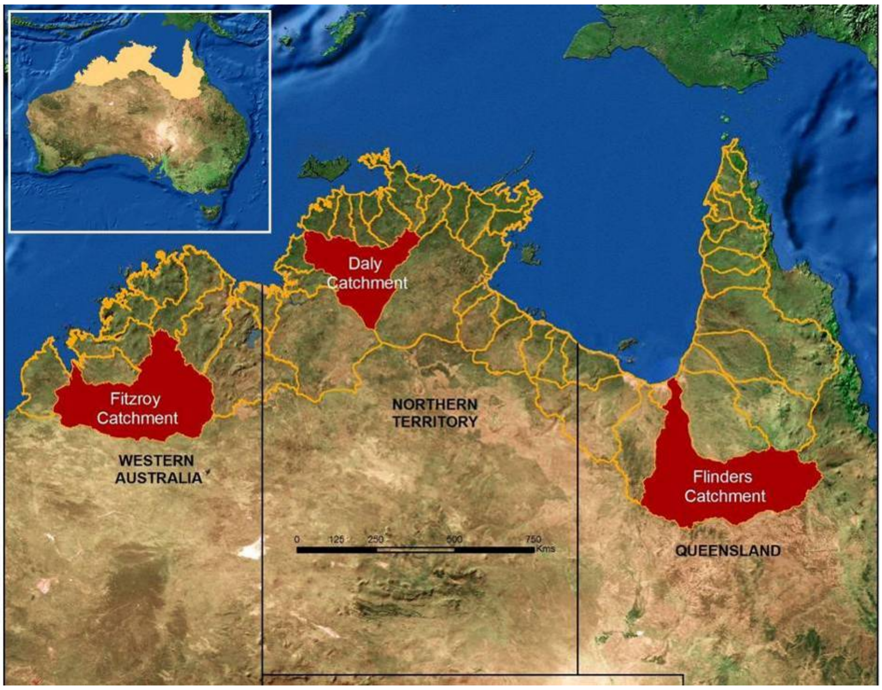

Figure 1.2 The Northern Tropical Rivers of Australia. The three focus catchments are shaded red.

1.3 Ecological risk assessment

1.3.1 Overview

Ecological risk assessment (ERA) is the process of predicting or estimating the likelihood and magnitude of adverse ecological effects occurring as a result of one or more threats (also referred to as stressors – see *Terminology*, below) (US EPA 1998; Burgman 2005). It provides a structured, iterative approach for making rational and transparent decisions based on the best available knowledge and recognition of the associated uncertainties. A generic paradigm for ERA is shown in Figure 1.3, and is the basis for the framework developed for this project. Generally, ERA encompasses the following steps – *problem formulation/hazard identification*, *analysis*, which consists of effects (consequences) assessment and exposure (likelihood) assessment, and *risk characterisation* (Figure 1.3), which are described below. Additional steps, such as risk communication, risk reduction and monitoring are also critical in the overall decision making process and are necessary to complete the risk management cycle (Burgman 2005). Moreover, identification and quantification of the key uncertainties and knowledge gaps enables prioritisation of research and data acquisition, which, through iteration of the risk assessment, decreases uncertainty in the risk predictions.

Applications of ecological risk assessment are numerous and include assessments that range from: screening-level (qualitative) to detailed (quantitative) or a combination of both (ie. tiered ecological risk assessment); predictive to retrospective in temporal scale; local to global in spatial scale; and single threat to multiple threats (US EPA 1998; Burgman 2005). Increasingly, risk assessment is being used in a catchment or basin context, to assess, prioritise and manage multiple threats, pathways, ecological resources/assets and competing social values (Aspinall & Pearson 2000; Serveiss 2001; Hart 2004).

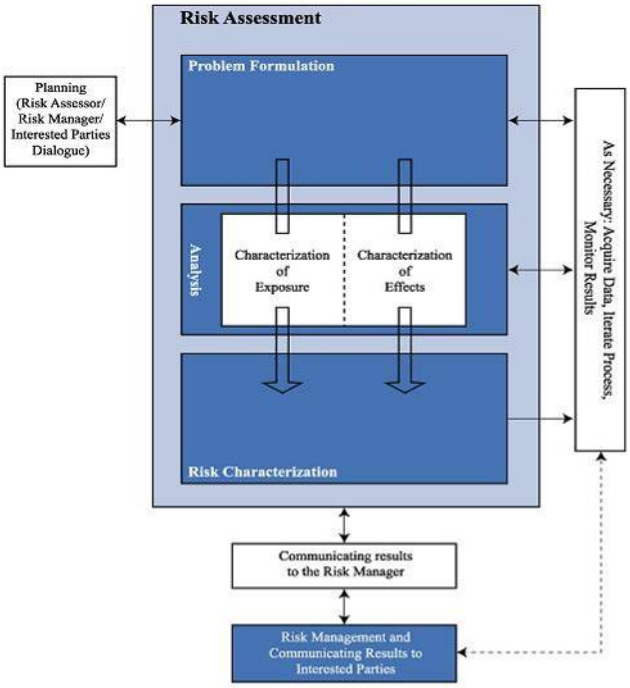

Figure 1.3 General framework for ecological risk assessment (modified from US EPA 1998).

1.3.2 Terminology

Consistency and clarity in terminology for risk assessment is crucial. Inconsistencies and lack of clarification can lead to miscommunication and incorrect interpretation amongst stakeholders (Burgman 2005). Table 1.1 lists definitions of common terms that are used and their intended use for this project.

Risk assessments focus on how (or if) certain agents or processes might affect things that are valued and need to be protected. However, the terminology used to define these two components can differ between risk assessments. This project uses the terms *ecological asset* (or simply *asset*) to define an attribute of a natural ecosystem that the community values and wants to see protected, and *threat* to define an agent or process (including an action or activity) that could adversely affect the asset and its values. The term *value* (or *ecological value*) in this context refers to the specific reasons an asset is considered important. An asset can have multiple values, which can be vastly different for different stakeholders. For example, a series of permanent river pools on a seasonally flowing river might be valued by someone for its good recreational fishing, by someone else because it provides crucial habitat for a threatened species, and by someone else because it holds great spiritual value. This study focuses on ecological values whilst recognising their links with other values (eg. cultural, economic) where they exist. We have chosen to use the terms *assets* and *threats* largely because they are consistent with the terminology used in the Integrated Natural Resource Management (INRM) planning processes currently underway in northern Australia and funded under the Natural Heritage Trust (NHT). This will hopefully facilitate the link between the assessments conducted under this project and the on-the-ground INRM programs. It is also important to note that threats arise from *pressures* (or *environmental pressures*), which are defined as human activities (eg. mining, urban development) and human-induced trends and patterns of environmental significance (eg. climate change and sea level rise) that have the potential to impact the natural environment.

Table 1.1 Definitions of terms used in risk assessment.

Term	Definition	Reference	Context for this study
Ecological Assets	Attributes (eg. components, processes, functions, products) of natural ecosystems, which are valued by the community (eg. river, wetland, biodiversity, environmental flow, water supply, primary production).	Modified from Hart et al (2005)	Used as defined.
Ecological Values	Qualities or characteristics of ecological assets that make the community value and want to protect them (eg. an ecologically healthy river; a biologically productive wetland; an upland stream rich in endemic fauna and flora).	Modified from Hart et al (2005)	Used as defined.
Ecosystem services	The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life. They maintain biodiversity and the production of ecosystem goods (eg. seafood, forage timber, biomass fuels)	MEA (2003)	Relevant to, but not used to a great extent for, this study.[1]
Endpoint	*Assessment endpoint* – explicit expression of the actual environmental value(s) to be protected (eg. invertebrate community diversity). *Measurement endpoint* – measurable responses to a threat that can be correlated with or used to predict changes in the assessment endpoints (eg invertebrate reproduction, macroinvertebrate monitoring).	US EPA (1998)	Used as defined.
Hazard	The potential, or capacity of a threat to cause adverse effects on man or the environment, under the conditions of exposure.	US EPA (1998)	Used as defined
Pressure	Any human activity or biophysical pattern of change that has the potential to impact the natural environment. “Pressures” here cover underlying or indirect pressures (ie. human activities themselves and biophysical trends or patterns of environmental significance) as well as proximate or direct pressures (ie. the use of resources and the discharge of pollutants and waste materials).	Adapted from OECD (2003)	Used as defined.
Risk	The probability of occurrence of an adverse effect of specific magnitude and timeframe on man or the environment resulting from a given exposure to a stressor.	Adapted from US EPA (1998) & Burgman (2005)	Used as defined.
Stakeholder	An individual or a representative of a group affected by or affecting the issues in question.	Glicken (2000)	Used as defined.
Stressor	Any physical, chemical, or biological agent or process arising from a pressure, which can induce an adverse environmental response.	US EPA (1998)	Synonymous with *Threat*, and generally not used for this study.
Threat	As above for *Stressor*, OR An action or activity that has the capacity to adversely affect an ecological asset and its value.	 Hart et al (2005)	Used as defined for *Stressor*.

[1] The term “ecosystem services” was used extensively for TRIAP Sub-project 3 (De Groot et al 2008).

1.3.3 The risk assessment process

The key steps in the ERA process are briefly explained below.

Problem formulation/hazard identification

Problem formulation or hazard identification involves the collation of existing information to determine the nature of the issue or problem. At the outset, decisions need to be made and clearly articulated on the specific objectives and scope of the risk assessment (eg. qualitative or quantitative analysis of a single or multiple threats to a single or multiple environmental assets; determination of spatial and temporal scale). These decisions will guide the type of data and information that need to be gathered, and help to identify knowledge gaps. Typically, existing information needs to be compiled for the following:

- the environment of interest, particularly its most important assets (and their values), or at least those that need to be protected or are potentially at risk;
- the threat(s) to which the environmental assets are, or may be, exposed; and
- the types of effects that the threats(s) may have on the environmental assets.

The synthesis of such information should be done in consultation with stakeholders through an agreed process. It is possible that the information may reveal that the scope and objectives need to be refined or more clearly articulated. This is one example of the iterative nature of ERA. Once the information on the relevant assets and threats has been acquired, the next step is to construct a hazard matrix, identifying specific threats that will potentially cause adverse effects on specific assets (or values) (see Chapter 2). A following step would be to identify the types of effects on the assets that could be caused by the threats, and based on this, determine relevant, and measurable endpoints on which the ERA will focus. Such endpoints are often referred to as *measurement endpoints* (US EPA 1998; see Table 1.1), and they represent measurable (and ecologically relevant) indicators of the environmental assets to be protected (US EPA 1998). The relevant information is then brought together to develop a conceptual model of the issue or problem.

Conceptual models are abstractions of the key issues, which can be presented in numerous ways, but often as flow (box or arrow) diagrams. They represent the current understanding of the relationships between the threat(s) and environmental asset(s), and are used to develop working hypotheses that guide the remainder of the risk assessment (Solomon et al 1996, US EPA 1998). Consequently, conceptual models are critically important components of risk assessments, as the assessments can only be as adequate and appropriate as the conceptual models on which they are based (Burgman 2005).

Analysis – effects (consequences) and exposure (likelihood) assessment

The analysis phase incorporates both effects assessment and exposure assessment. These are described separately, below. For both components, the most pertinent information sources and techniques should be used, although these will vary depending on the assessment. Some types and sources of information include (AS/NZS 2004a, b):

- past records, including relevant published literature;
- experiments and investigations;
- modelling;
- practice and relevant experience;
- the results of public consultation; and
- specialist and expert judgements.

Effects and exposure assessment are often carried out con-currently and in an iterative fashion: simple assessments are often performed initially, followed by more comprehensive (eg. quantitative) assessments if considered necessary (van Dam et al 1999). The outputs of the effects and exposure assessments should be cross-checked with stakeholders to ensure that data and information were used and interpreted appropriately.

Effects (consequences) assessment

Effects assessment aims to determine the impacts or consequences of the threat(s) on the measurement endpoints selected during problem formulation (van Leeuwen 1995, US EPA 1998). For example, reduced water quality (for whatever reason) might impact aquatic ecosystems as measured by reduced species diversity and abundance of macroinvertebrate and/or fish communities. The magnitude of impact should be quantified to the extent possible.

Exposure (likelihood) assessment

Data on the effects of a threat to an asset (or appropriate endpoint) provide little useful information without knowledge on the actual level of exposure of the asset to the threat. Thus, exposure assessment aims to determine the likelihood that the ecological asset(s) will be exposed to the threat, and therefore, that an effect will be realised. For a biological threat, such as an invasive weed, exposure assessment might involve integrating information on the source of the weed, the potential route of entry into the ecosystem of interest, rate of spread, habitat preferences, and associated distribution. Existing information (eg. remotely sensed imagery) or habitat suitability modelling can be used for such purposes.

Risk characterisation

This step integrates the outcomes of the effects (consequences) and exposure (likelihood) assessments in order to determine the level of risk (ie. consequences × likelihood). In general, there are three levels at which this analysis of risks can be undertaken: *qualitative*; *semi-quantitative*; and *quantitative*. Often, risk assessments are undertaken in a tiered manner, with initial screening-level qualitative or semi-quantitative analyses being done prior to more detailed quantitative analyses (Burgman 2005). The purpose of this is to first rank the threats and associated hazards so that more effort can be allocated to quantitative risk analyses for the most important (ie. highest priority) threats and associated hazards. This is the approach proposed for this study, and is described in more detail in the next section. Whilst the output of risk characterisation need not be a quantitative estimate of risk, sufficient information should, at the very least, be available for appropriate experts to make judgements based on a weight-of-evidence approach. In the event of insufficient information being available, it is possible to proceed with another iteration of one or more phases of the risk assessment process in order to obtain more information (US EPA 1998). Regardless of the approach, uncertainty associated with the risk assessment must always be described and, if possible quantified, while interpretation of the ecological significance of the conclusions must also be carried out (Pascoe 1993, US EPA 1993). In addition, the risks must be sufficiently well defined to support a risk management decision, as discussed below.

1.4 Project objectives and scope

The objectives of the project were three-fold:

1. to identify and describe the key threats, including their significance, to the aquatic ecosystems of the Northern Tropical Rivers;

2. to identify, determine the significance, and where possible, quantify the risks of key threats to key ecological assets of the aquatic ecosystems of the Daly River catchment;

and in doing so,

3. illustrate the application and utility of ecological risk assessment as a decision making tool for natural resource management.

A hierarchical and tiered approach was adopted for the risk assessments, with analyses at increasing levels of detail/quantification as spatial scale became smaller. This is depicted in Figure 1.4, with the three tiers described representing the subject of Chapters 2, 3 and 4 of this report, respectively.

The risk assessment framework (described above and in Figure 1.4) and associated risk analysis approaches (described in Chapters 3 and 4) adopted for this project were not new and have been well described elsewhere (eg. Landis & Wiegers 1997; US EPA 2003; Bayliss et al 2004; Burgman 2005; Hart et al 2005). Importantly, it was not the intention of the project to develop a new risk assessment framework for application to tropical rivers, but to promote the use of a tiered risk assessment framework and demonstrate the application of various specific risk assessment approaches for specific purposes, for making decisions in natural resource management.

Several assessments were undertaken, as follows:

Northern Tropical Rivers study area

- Semi-quantitative relative risk assessment of threats to the aquatic ecosystems of the 51 tropical river basins

Daly River

- Semi-quantitative relative risk assessment of multiple threats to multiple assets
- Quantitative risk assessments of several key threats to selected assets

At the start of the project, the original intent had been to also undertake some level of semi/quantitative risk assessment for the Fitzroy River catchment (WA) and the Flinders River catchment (Qld). However, the project's resources did not enable the completion of these assessments other than initial descriptions of the key ecological assets and threats, and an associated asset-threat matrix.

The focus for the identification of ecological assets and their values was on those aspects that directly relate to health of surface water ecosystems (ie. the river and its associated surface wetlands and riparian habitats). Due to resource constraints, socio-cultural assets and values were not implicitly included in the assessment, although such aspects were identified and acknowledged where these had been flagged by the consultation process and when there was overlap with ecological assets and values. Nevertheless, we emphasise that for complete 'environmental' risk assessments of pressures to be deemed credible and ultimately accepted by the general community in northern Australia, socio-cultural risks (ie. risks to socio-cultural assets and values) need to be characterised and embedded in the ERA process.

Identification and description of social, cultural and economic values of northern rivers has recently been, and is currently being, undertaken by other research groups, and for such information, readers are directed to key reports by Jackson et al (2005), Jackson & O'Leary (2006) and Stoeckl et al (2006), as well as other materials identified in Chapter 2.

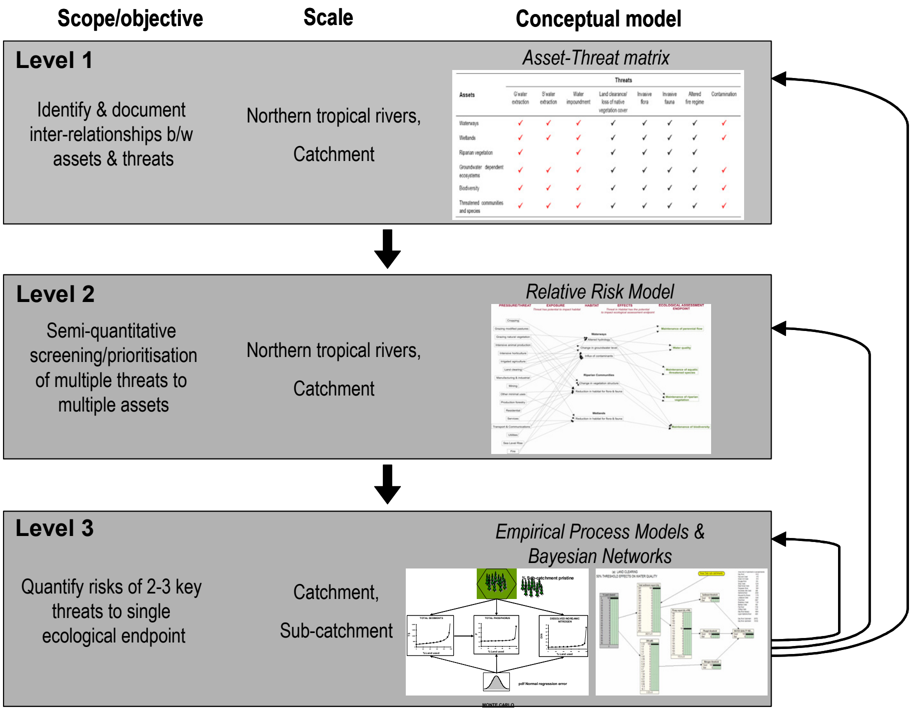

Figure 1.4 Hierarchical and tiered approach adopted by this study for conceptual model development and associated risk assessments. Although not part of this study, the arrows represent feedback loops for iteration of previous conceptual models and risk analyses, to reduce uncertainty.

In general, the assessments focused on the potential risks posed by *current* land and water use. However, scenarios of future pressures were included for sea level rise due to climate change (semi-quantitative relative risk assessments; see Chapter 3) and flow extraction, land clearing and weed invasion in the Daly River catchment (quantitative risk assessments; see Chapter 4).

1.5 Linkages to other TRIAP Sub-projects

As stated above, this study represents one of three Sub-projects undertaken through the TRIAP. At the outset of the TRIAP, Sub-project 1, *Inventory of the biological, chemical and physical features of the aquatic ecosystems of the Northern Tropical Rivers* (Lukacs & Finlayson 2008), and this project were strongly linked through the concept of the integrated WIAM framework (Finlayson et al 2005; see Section 1.1). The key linkage is that the inventory data (ie. Sub-project 1) should be able to be used directly for the assessment phase (ie. this project). Thus, the GIS database for the risk assessments needed to be able to link to, or ideally, be a part of, the GIS for the inventory (Sub-project 1). Much of the data and associated analyses from Sub-project 1 were used in this project as information about ecological assets. Data and information on pressures and threats were compiled through the risk assessment study, as well as a considerable amount of additional ecological assets data and information to supplement that acquired from Sub-project 1.

The linkage with Sub-project 3, *Development of a framework for the analysis of ecosystem services provided by aquatic ecosystems* (De Groot et al 2008), was less formal, given its site-specific 'case study' focus and primary objective of trialling a framework for valuing ecosystem services. Nevetheless, it is not unrelated to this study, and information from Sub-project 3 was included in this study where relevant and appropriate.

Chapter 5 (Section 5.1) provides a retrospective appraisal of the linkages of this study with the two other Sub-projects, in particular: (i) the utility of the WIAM concept in relation to Sub-project 1; and (ii) the possible inter-relationships between the ecological risk assessment framework and associated approaches, and the ecosystems services framework applied in Sub-project 3.

1.6 Report outline

The remainder of this report is structured as follows:

Chapter 2 (*Identification of ecological assets, pressures and threats*) details the aquatic ecological assets of the four study regions (ie. Northern Tropical Rivers study area and three focus catchments), and the pressures on, and associated potential threats to, these assets. Simple asset-threat matrices are produced for each study region that represent a 'first pass' conceptual model.

Chapter 3 (*Semi-quantitiative risk assessments – the Relative Risk Model*) draws on information from Chapter 2 and elsewhere, and details the semi-quantitative relative risk assessments of multiple pressures/threats to multiple ecological assets for the Northern Tropical Rivers study area and the Daly River catchment.

Chapter 4 (*Quantitative ecological risk assessments for the Daly River*) draws on information from Chapters 2 and 3 and elsewhere and, focusing on the Daly River, details three quantitative risk assessments as follows:

- Risks of water extraction and weeds on floodplain health (magpie goose nesting and refugia habitat; plant biodiversity);
- Risks of water extraction on in-stream health (barramundi catch and population abundance); and
- Risks of land clearing on surface water quality (sediment and nutrients).

Chapter 5 (*Synthesis and recommendations*) synthesises the key outcomes and discussion points of the study mostly in relation to the utility of the risk assessment framework. It covers critique of the specific risk assessment approaches, dealing with uncertainty, information gaps, linkages with TRIAP sub-projects 1 and 3, and recommendations for future research investment.

1.7 References

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