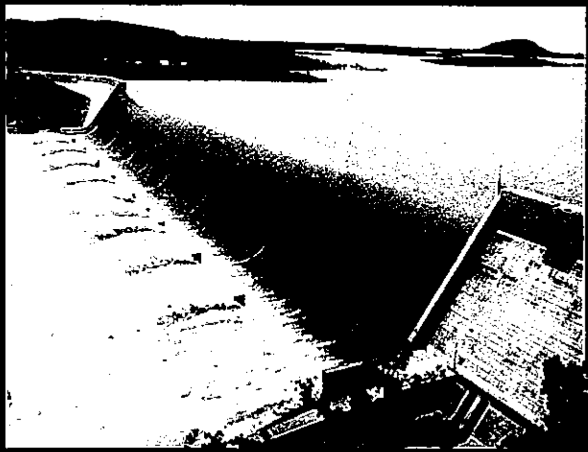

The North Australia Program

Catchment Management, Water Quality and Nutrient Flows & the Northern Australian Beef Industry

Edited by Rosemary Hook

Land and Soil Consulting

NAP Occasional Publication No. 3

MEAT & LIVESTOCK AUSTRALIA

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Disclaimer

This report was prepared as a basis on which to develop further research to assist with the sustainable management and use of the grazing lands of northern Australia. Every effort has been made to ensure that the information provided in this report is current at the time of publication. The participating organisations and persons associated with this report do not assume liability of any kind whatsoever resulting from the use of or reliance upon its contents. Independent professional advice on all matters discussed in this report should be obtained prior to making any decision based on information summarised in this report. The views expressed in this report should not necessarily be taken to represent the views of the participating organisations.

PREFACE

Meat and Livestock Australia acknowledges the excellent work of Rosemary Hook and her colleagues who conducted this review. Rosemary and her collaborating authors brought together literature and unpublished information dispersed across a diversity of sources and have provided a comprehensive overview of literature and current research on catchment management, water quality and nutrient flows as they relate to the beef industry in northern Australia.

The report provides a substantial basis for commissioning a scoping study to identify an appropriate focus catchment for a major collaborative research project and to better define research and development priorities on the relationships between grazing management, water quality and nutrient flows. Following on from this report, a scoping study (NAP3.223) has recently been completed by a multi-disciplinary team led by Dr Christian Roth, CSIRO Land & Water. This work will be published as NAP Occasional Paper No. 4 and work is now under way to commission a major research and development project.

This initial review work was commissioned in April 1997 and this report was submitted to the MRC in October 1997. It was jointly funded by the then Meat Research Corporation and the Land and Water Resources Research and Development Corporation, under Phase 3 of the MRC's North Australia Program.

Meat and Livestock Australia and the authors thank all those, both individuals and organisations, who generously contributed their time and information to this review.

Judy Lambert
Natural Resource Management Consultant
MRC North Australia Program

September 1998

ACKNOWLEDGMENTS

This overview would not have been possible without the willing and generous assistance of very many people. I had originally intended to put with the review a list of the people who were contacted and provided information, but so many people have helped this was not considered feasible. To all those people who gave me, and those on the review team, so much of their time, often at such very short notice, I express my sincere thanks. I also wish to thank those who helped with the component reviews — I know that for most, this involved many hours outside the normal working day. Their commitment and interest have been keenly felt and very much appreciated. I also thank Heather Hunter (Queensland Department of Natural Resources) for the written sections on Queensland monitoring programs that have been incorporated in Review 5.

The workshop convened by the Meat Research Corporation to review the draft report, held in Brisbane on August 7th, 1997, provided invaluable feedback. This final report incorporates many of the suggestions and comments made at the workshop and the time and input of those attending the workshop is acknowledged with gratitude. In particular, I would like to thank Barry Walker (NAP3 program coordinator) and Annemarie Watt (Environment Australia) for written comments on the draft report. It has not been possible to include all changes suggested at the workshop and others have no doubt been inadvertently overlooked. I apologize for these omissions. John Aldrick (CSIRO Land and Water) kindly reviewed several chapters in the final report and his many helpful suggestions are gratefully acknowledged. Finally, I wish to thank the project steering committee for their guidance, advice and assistance throughout the project.

Rosemary Hook
Land & Soil Consulting

FOREWORD

Extended dry seasons combined with changed cattle production systems have placed increased pressures on native pastures across much of northern Australia over the past 25 years. Concurrent with these changes, there is an increased awareness of the interactions between downstream siltation, altered environmental flows in rivers and streams and impacts on tourism destinations such as the Great Barrier Reef, and on commercial fisheries breeding grounds in coastal estuaries.

In moving to define 'best practice' within the northern Australian beef industry, account must be taken of the whole range of interactions between the industry and the environment in which it operates. Both direct impacts on natural resources and indirect impacts such as nutrient or chemical contamination, or the stimulation of algal or microbiological proliferation are of significance, as are the impacts of environmental change on productivity. In many instances indirect impacts are shared effects of beef production and other primary industries within the same catchment, with little emphasis having yet been placed on these various responsibilities.

It is important to minimise potential conflict between differing sectors of industry in Australia to assist in moving production in this country to a more ecologically sustainable basis. Bringing together the knowledge of scientists, producers and those responsible for the management of water resources to provide a whole catchment perspective on sustainable management will play an important role in this.

These issues are of concern Meat and Livestock Australia (incorporating the former Meat Research Corporation) and the Land & Water Resources R&D Corporation through Phase 3 (1996-2001) of the North Australia Program, which seeks to "improve the profitability, international competitiveness and ecological sustainability of beef production in northern Australia". The North Australia Program is seeking firstly to catalyse improved understanding and more effective application of existing principles and indicators of ecologically sustainable grazing systems. Secondly, it seeks to integrate knowledge of the impacts of grazing management strategies into the development of management systems that deal with environmental threats and opportunities so that the whole industry becomes ecologically sustainable.

It is in this context that the then Meat Research Corporation and the Land & Water Resources R&D Corporation came together to jointly commission a review of current information on catchment management, water quality and availability and the movement of nutrients from grazing land to the water cycle. Interactions between grazing management, drought, vegetation cover, soil erosion and downstream effects on water quality and availability form the primary focus of this review.

The review team was led by Rosemary Hook of Land & Soil Consulting, who brought together a rich diversity of both published and unpublished literature, and recruited and coordinated technical papers from the various researchers involved. Rosemary met with members of the North Australia Program management group (which includes representatives from both the Land & Water Resources R&D Corporation and Environment Australia's Biodiversity Group) to plan the review process. Feedback on a draft report was provided through a workshop involving relevant research scientists, northern beef producers with a demonstrated interest in catchment management issues and members of the project management group. Following internal reviewing by NAP management, the final report was also submitted to an independent senior scientist active in catchment management and water quality issues for peer review.

EXECUTIVE SUMMARY

Extended dry seasons over several years combined with changed cattle production systems have placed increased pressure on native pastures across northern Australia. Over the past twenty years stocking rates in some areas have begun to exceed 'safe' carrying capacities resulting in undesirable changes in pasture composition, and soil degradation. The increases in grazing pressure have coincided with an increasing awareness that the changed processes in the land that lead to pasture and soil degradation, can also affect water quality of the catchment. There is particular concern about the off-shore effects that changes in river water quality may be having. Such effects may involve, for example, increased sediment and nutrient inputs degrading the estuarine breeding grounds of commercial fisheries or changing the ecology of coral reefs. This concern is illustrated by the several conferences and workshops that have been held to discuss the changes in, and effects of, terrigenous inputs to the Great Barrier Reef lagoon, and by the formation in Queensland of the Downstream Effects of Agricultural Practices (DEAP) committee.

There is also increasing awareness of the need for Australian industries to be productive and economically viable, but not at the expense of degrading our natural resources so as to impair their capacity for use, including use by future generations. This need has been enunciated in the principles of ecologically sustainable development. As a result of the increased awareness within the community of the need to maintain the productivity of our natural environment, there are increasing requirements for agricultural commodities to be produced so as not to cause degradation of our biota, and land and water resources. It is becoming more and more incumbent on agricultural industries to demonstrate that their management practices are not degrading the environment.

It is now well understood that catchment water quality and its implications for downstream biota and water use, are the result of all activities within a catchment. This has led to the concept of Integrated or Whole Catchment Management and the development of catchment management groups. The aim of these groups is to develop catchment management strategies and plans to ensure that management is integrated and that the different land uses are not detrimentally affecting other industries. While the management of grazing lands must take place within a whole catchment framework, it is also essential that the off-site effects attributable to particular grazing practices be separated from those caused by other industries, or which occur naturally. By being in possession of the facts, the industry can take proper and realistic responsibility, and develop a strategic position for the future which will enhance its competitiveness, particularly internationally.

These issues are of concern to the Meat Research Corporation and the Land and Water Resources Research and Development Corporation and are being addressed in Phase 3 of the North Australia Program (NAP3). Phase 3 follows Phase 1(commenced in 1986) and 2, and extends from mid 1996 to mid 2001. The North Australia Program, which is jointly funded by the Meat Research Corporation and the Land and Water Resources Research and Development Corporation, seeks to "improve the profitability, international competitiveness and ecological sustainability of beef production in northern Australia".

International competitiveness has been addressed by examining the determinants of competitiveness and concluding, among other things, that adoption of acceptable environmental standards will be fundamental to the future of the industry. Subprogram 2 of NAP3, Improving Resource Management, aims to increase international competitiveness and hence profitability, by improving the development and adoption of ecologically sustainable resource management systems and their profitable utilization by the northern Australian beef industry.

To assist in developing a relevant program of research for NAP3, the Meat Research Corporation and the Land and Water Resources Research and Development Corporation jointly commissioned a broad overview of current information on the effects of catchment use and management in the grazing lands of northern Australia, on water and nutrient cycles and the downstream fluxes of water, sediment and nutrients. Interactions between grazing management (primarily stocking rates and their variation in time and space), drought, clearing and pasture improvement in producing these effects, were regarded as particularly important. Also important were the effects of these changes on the ecological status of riverine, estuarine and marine ecosystems, although the review was not concerned with impacts upon biological diversity more generally as this has been the focus of another project within NAP3. As well as reviewing current knowledge, the commissioned review was also required to recommend work which might appropriately be funded by NAP3 and to prepare a draft report for review by a forum of northern Australian beef producers and others with responsibilities in natural resource management.

A large amount of research relevant to this topic has been undertaken and it was not possible in the time-frame available to comprehensively review all material. The aim has been to identify major gaps in understanding and knowledge. Most research to date has involved understanding the effects of particular stocking regimes on pasture composition and water, sediment and sometimes nutrient fluxes. Generally, this work has been for plots or small catchments. There has also been some work identifying the effect of clearing and pasture improvement on components of the water balance. The terrestrial inputs from catchments flowing into the Great Barrier Reef lagoon, the fate and effect of these inputs, has also received some attention. Estimations of terrestrial inputs and their change following the introduction of grazing, have been based on fluxes measured for plots or small catchments or on extrapolations from rivers and streams for which sediment concentration and flow data are available. A very limited amount of work is currently underway using coral and sediment cores to investigate temporal changes in terrestrial inputs from catchments on the east coast of Queensland. The issue of the degree to which the introduction of grazing has increased sediment and nutrient fluxes to the marine environment over and above natural inputs, and the effect of this increase, particularly on the Great Barrier Reef, remains equivocal.

Despite the large amount of research that has been undertaken, major gaps in knowledge remain, which is not surprising given the vast area covered by the northern Australian beef industry. Areas of particular concern are:

- the paucity of research investigating the effects of grazing and grazing land management on wetlands and riparian areas; qualitative subjective assessments based on observation are numerous but there are few data that quantify the changes that have occurred;
- the major gaps in our knowledge of the interactions between the various components of the grazing system, their variation for different land types, and in time and space within a given land unit — past work has focussed predominantly on pasture—animal interactions; in future, consideration also needs to be given to vegetation—nutrient—soil biota interactions and soil—pasture condition—water inter-relationships;
- the scant research in processes for areas larger than plot and small catchment — this reflects the 'grazing trial' nature of much research carried out to date; for example, apart from studies of the effect of the distribution of watering points, there has been little investigation of animal behaviour and its effect within paddocks, or of the time it takes for local changes in the flux of water, sediments and nutrients as a result of grazing management practices to have an effect on fluxes from the whole catchment;
- the lack of information on components of the water balance and changes in the flux of water, sediment and nutrient, relating to particular landscapes (land with similar climate, geology, topography, regolith and soil, and vegetation); also of concern is the fact that relatively little use seems to be being made of land system data although land information is critical to assessments of land productivity and its inherent susceptibility to degradation; and
- the apparent non-awareness within the grazing industry as a whole, of the need to adjust stocking rates, both in space and time, to match pasture productivity, and of the degradational consequences of not doing so both on the land on which the pastoral enterprise depends, and on the water resources downstream.

Given the large gaps in knowledge in many areas relevant to understanding the effects of the northern Australian beef industry, there are several recommendations which could be made for appropriate work. The following specific recommendations reflect the outcome of discussions arising at the workshop held in Brisbane, to review the draft report.

Recommendations

The first two recommendations are for more preliminary work to be undertaken before development of the final research proposal. The third recommendation relates to the type of research to be undertaken.

Further information on current projects

Current projects related to water and nutrient movement, and catchment management more generally, need to be assessed to identify more specifically the knowledge that is being obtained and any deficiencies of the work. This will require the collection of further details on the problems being addressed, project objectives, methods being used, where the work is being undertaken, the organization that is doing it, the timescale and the sources of funding. Projects from Phase 2 of the North Australia Program (NAP2) that are being extended into NAP3 need to be included.

Identification of appropriate catchment(s) for research

Given that major research will need to be limited to one or two catchments as a result of funding constraints, an important issue is the catchment(s) in which the research should be done. A scoping study that considers all catchments across northern Australia needs to be undertaken as a matter of priority. As a starting point, the study needs to establish the criteria against which catchments would be ranked and grouped. Some of the suggested criteria are:

- a perceived high potential for the grazing industry to affect land and water quality;
- a catchment community that wants the sort of information that will be generated by the research;
- a catchment that is considered to be important from the point of view of the grazing industry; and
- an effective extension process already in place to pick up research results and incorporate them into catchment planning.

The first criterion requires characterisation of catchments in terms of biophysical attributes, including geomorphology, climate and land use, in an attempt to identify potential vulnerability to degradation and risk of off-site effects. Also important are whether catchments are coastal or inland and whether rivers are regulated or unregulated. It is also recommended that this scoping project assess the land system and other resource mapping information available across northern Australia. Note should also be made of catchments in which NAP3 projects arising from NAP2 projects, are being undertaken.

Recommended research

The third recommendation is to establish a project or projects to identify and measure the significant effects that the north Australian beef industry is having on the movement of water and nutrients within the catchment and the effect of this movement on water quality and the sustainable use of other resources.

It is recommended that the research involve:

- an analysis of the surface hydrology, landforms and patterns of sediment generation, transport and deposition, and the delineation of geomorphic provinces;
- an interpretation of the inherent capacity of the geomorphic provinces to supply sediment and nutrients to the major river systems and the susceptibility of the land within them to degradational processes as a result of specific grazing practices;
- establishing budgets for water and key nutrients at paddock to catchment scales, using the provinces as a guide to major landscapes for which budgets are required;
- examining the extent to which grazing and grazing management practices enhance loss (as distinct from redistribution) of water, sediment, nutrient or organic matter, from local areas (ie, catchment divide to water course); and
- determining the effect any such losses are having on land functioning and productivity, both on and off site.

It was recognized that this project needs to be linked with the biodiversity research that will be funded in NAP3.

1. INTRODUCTION

1.1. Background

Extended dry seasons over several years combined with changed cattle production systems have placed increased pressure on native pastures across northern Australia over the past twenty or so years [see, for example, Tothill and Gillies (1992) and Williams *et al.* (1993)]. Until the 1970s, the rangelands were grazed at low stocking rates by British breeds of cattle which were poorly adapted to the tropics. In drought years with low pasture production, animals died if stock numbers were not reduced, with the result that cattle herds tended to naturally readjust to the prevailing conditions (Figure 1.1). During the 1970s, *Bos indicus* cross-breeds which were better adapted to dry conditions, were introduced. The greater capacity of these breeds to survive dry periods, aided by diet supplementation with non-protein nitrogen and minerals, resulted in large increases in herd sizes by the late 1970s (Figure 1.2). In addition to increased herd numbers, improved transportation allowed cattle to remain on properties for longer during droughts and to return from agistment sooner. As a consequence, stocking rates began to exceed 'safe' stocking rates and this has resulted in undesirable changes in pasture composition and soil degradation (Tothill and Gillies, 1992).

The increases in grazing pressure have coincided with an increasing awareness that activities in one part of a catchment not only affect land condition and processes where they occur, but that the changed processes on land can also lead to changes in waterways and downstream waterbodies. There is growing concern that high grazing pressures and grazing land management are having detrimental effects not only on pastures and land condition but also on water quality. There is particular concern about the off-site effects that may result from inappropriate grazing management in catchments draining to the coast. Such effects may involve, for example, increased fluxes of sediments and nutrients degrading the estuarine breeding grounds of commercial fisheries and altering the ecology of off-shore reefs. The effect of terrigenous inputs of sediment and nutrients on the Great Barrier Reef, classified as a World Heritage Area, has received particular attention [see, for example, papers in the proceedings of recent conferences such as Downstream Effects of Land Use (Hunter *et al.* 1996); Great Barrier Reef: Terrigenous Sediment Flux and Human Impacts (Larcombe, P., Woolfe, K. and Purdon, R. 1996); The Great Barrier Reef: Science, Use and Management (Turia, N. and Dalliston, C., 1997)].

There is also increasing awareness of the need for Australian industries to be productive but not at the expense of degrading our natural resources so as to impair their capacity for use, including use by future generations. This need has been enunciated in the principles of ecologically sustainable development. Bringing together the knowledge of scientists, primary producers and others who use and manage the different catchment resources, will play an important role in ensuring that the development of our industries takes place within the bounds of the productive potential and susceptibility to deterioration of our land and water resources.

In moving to define 'best practice' within the northern Australian beef industry, account must be taken of the whole range of environmental effects of the industry. This includes both the direct effects on land (including the biota) as well as the indirect effects on waterways, such as chemical contamination or the stimulation of algal and microbial proliferation. In many instances, other primary industries and land uses located within a catchment can have similar effects on catchment resources. For this reason, management strategies are needed for whole catchments to ensure that there is integrated management of land, water and the associated biological resources, and that the different land uses are not detrimentally affecting other industries. While whole or integrated catchment management is essential, it is also necessary that the off-site effects due to grazing be separated from those caused by other industries, as well as from the changes which occur naturally. It is only in this way that the grazing industry can take proper but at the same time realistic responsibility for its actions. By being in possession of the facts, the industry will be able to adopt a strategic position for the future.

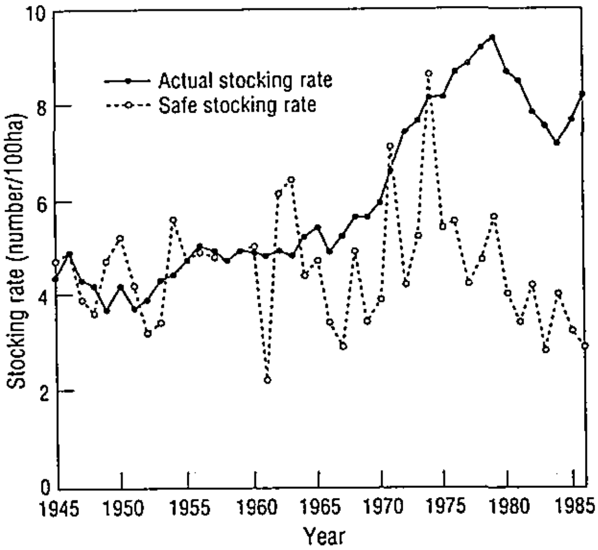

Figure 1.1. Actual and safe stocking rates for the period 1945-1985, Dalrymple shire, Qld. (from Pressland and McKeon 1990)

Safe stocking rate = summer pasture growth (kg/ha Dec-May) x 30% utilization / 6 months animal intake x shire index (accounts for effect trees)

Pasture growth: calculated using the GRASP model

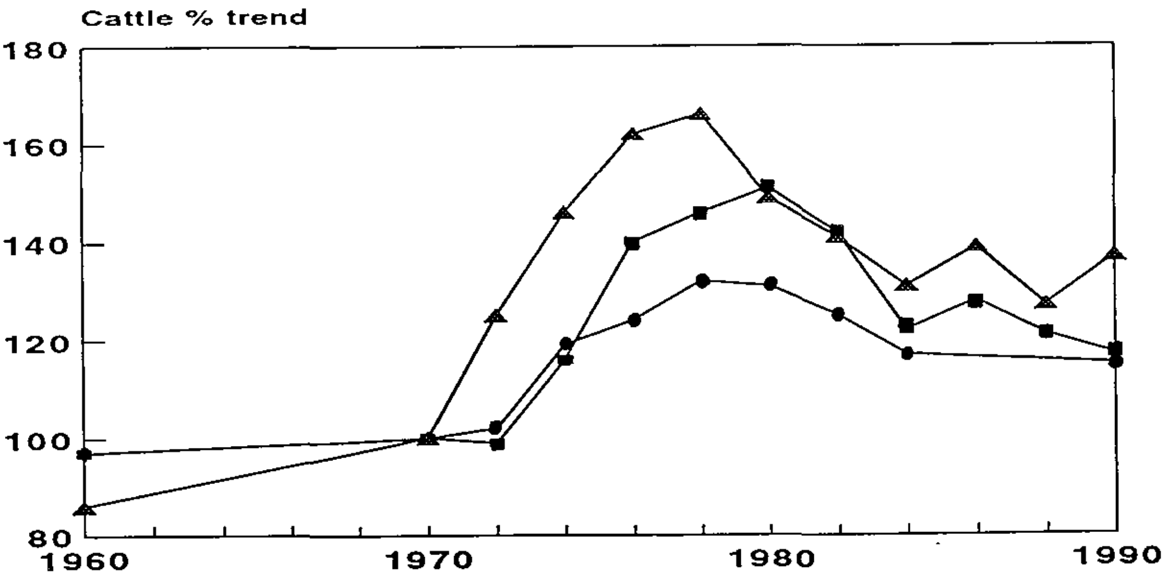

Figure 1.2. Relative changes in cattle populations from 1970-1990, using 1970 as a base. (From Tothill and Gillies, 1992)

▲ Queensland ■ Northern Territory ● Western Australia

These issues are of concern to the Meat Research Corporation (MRC) and the Land and Water Resources Research and Development Corporation (LWRRDC) and are being addressed in Phase 3 of the North Australia Program (NAP3). Phase 3 follows Phases 1 and 2, and extends from mid 1996 to mid 2001. The North Australia Program, which is jointly funded by the MRC and the LWRRDC, seeks to "improve the profitability, international competitiveness and ecological sustainability of beef production in northern Australia". This is to be achieved through the operation of four sub-programs:
1. Meeting Market Requirements;
2. Improving Resource Management;
3. Improving Property Management; and
4. Improving Program Delivery.

International competitiveness has been addressed by examining the determinants of competitiveness and concluding, among other things, that adoption of acceptable environmental standards will be fundamental to the future of the industry. Subprogram 2, Improving Resource Management, aims to increase international competitiveness and hence profitability, by improving the development and adoption of ecologically sustainable resource management systems and their profitable utilization by the northern Australian beef industry. The key issues to be addressed by the subprogram are:
- the need to understand and more effectively apply existing principles and indicators of ecologically sustainable grazing systems;
- the need to continue and expand core investigations of the effects of grazing management strategies and to integrate them with activities promoting preferred strategies;
- the need to strategically position the northern Australian beef production sector to identify and deal with environmental threats and opportunities, including consideration of alternative resource management systems, should existing systems not be ecologically sustainable and profitable.

The principal strategies to address the key issues are:
- to identify and act on constraints and opportunities to improve the adoption of ecologically sustainable grazing systems;
- to apply and further develop ecological sustainability principles for profitable systems in particular agro-ecological regions; and
- to define and monitor the state of the soil, water and biological resources used or affected by the northern Australian beef industry.

2. Overview of catchment management, water quality and nutrient flows, and ecological effects as they relate to the northern Australian beef industry

In this context, the Meat Research Corporation and the Land and Water Resources Research and Development Corporation jointly commissioned a broad overview of current information on the effects of catchment management in the grazing lands of northern Australia, on water and nutrient cycles and the downstream fluxes of water, sediment and nutrients. Interactions between grazing management (primarily stocking rates and their variation in time and space), drought, clearing and pasture improvement in producing these effects, are particularly important. Also important are the effects of these changes on the ecological status of riverine, estuarine and marine ecosystems. Appendix 1 provides full details of the Terms of Reference for this review.

2.1. Scope of the review

2.1.1. Geographic area and regional variation

For the purposes of this overview, the effects of extensive grazing only are considered, not the effects of beef production from feed-lots. Grazing lands in northern Australia include those of Queensland, the Northern Territory and the north-west part of Western Australia (Figure 1.3.).

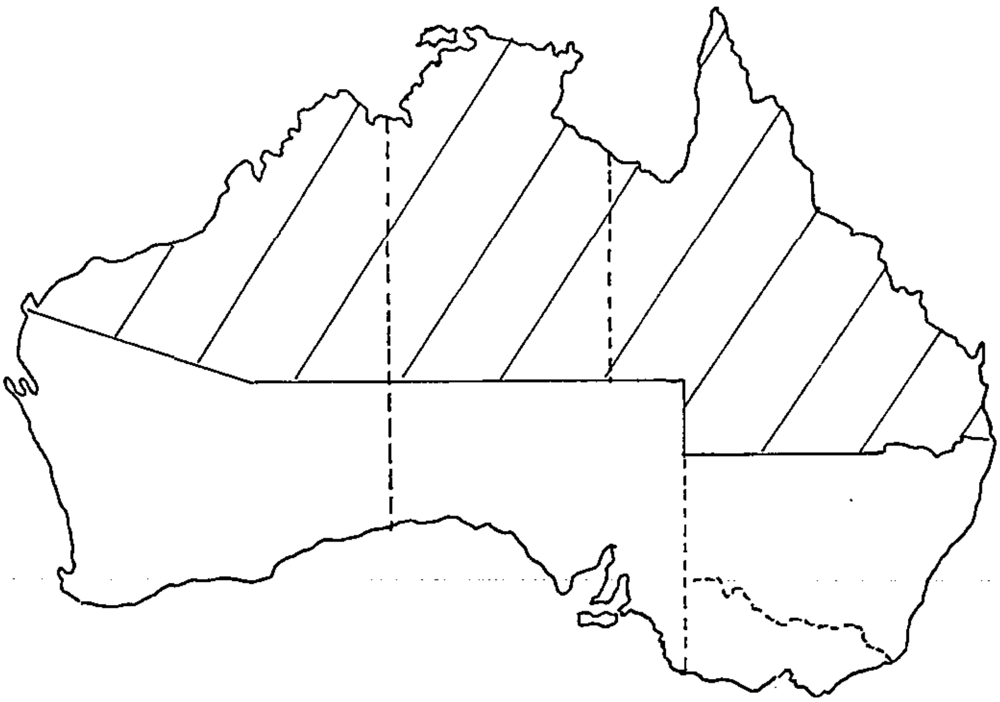

Figure 1.3. The area of northern Australia encompassed by this review

Encompassing such a large part of Australia, a wide variation in climate and landscape characteristics occurs throughout the region. The low latitude tropics have a more clearly defined summer rainfall pattern and rainfall declines from the coastal areas to the more arid inland. The variation in climate has a large influence on the hydrology of northern Australian catchments. Catchments draining to the coast occur in the more humid areas of northern Australia and mostly have pronounced high volume late summer flows that decline to low or zero flow over the winter, spring and early summer months. In contrast, the internally draining river systems, such as those of the Cooper, Diamantina and Georgina, are characterised by high flow variability which increases downstream. Discharge volumes also tend to decrease downstream. This pattern reflects the variable and erratic rainfall with increasing aridity inland, and the immense dispersal system of the floodplains (Morrish, R.B. 1996).

There is also enormous variation in geology and landform, and corresponding diversity in soils, vegetation and associated fauna. Clearly the effect of grazing management will vary considerably throughout northern Australia. Ideally an understanding of the effects of grazing management on the land and its biota, and the downstream ramifications, should consider the variation in catchment characteristics and landscapes. This has not been possible in this review due to the time constraints. Principles only are discussed, while the need for these to be translated with respect to specific catchments and landscapes is noted.

2.1.2. Biological diversity

"Biological diversity (often shortened to biodiversity) encompasses the variation that exists between individuals within a species, between populations of species, between species themselves, between communities, landscapes and ecosystems" (Lambeck, 1997). Retaining the natural biological diversity within a region is another issue that is being increasingly recognized as important. The importance derives from philosophic considerations and the view that human societies should not cause the decline and extinction of other organisms, as well as from practical and economic perspectives — we simply do not know the future needs and problems of society and the hitherto unknown benefits that particular biota, communities or ecosystems may provide for them.

The effect of grazing on the northern Australian native fauna and flora (which is taken as including all levels of biological organization from species variety through to ecosystems) is of increasing concern, as much of the biological diversity of northern Australia is not included in formal reserves. The lack of representation within reserves means that maintenance of a considerable proportion of the northern Australian biota will very often depend on the management of grazing and grazing lands. Management of grazing and grazing lands so as to conserve the biological diversity within northern Australia is a major issue for the Improving Resource Management subprogram and is the focus of a separate project to identify appropriate research for funding under NAP3. Consequently the effect of grazing on biological diversity generally was not a component of this review. The effects of grazing on riparian and wetland biota, however, are considered in the context of the off-site effects of grazing, and the effects of grazing on soil fauna and flora are part of understanding the effects of grazing on soil properties and processes.

2.1.3. Mathematical models

Mathematical models which are able to simulate plant growth and/or water and nutrient movement either at a point or within a catchment, are becoming useful tools with which to investigate the likely effects of particular management practices and grazing strategies. Such models are not systematically reviewed although modelling work is considered in relation to some processes. The view was taken that, since models can only be based on our understanding of system function, the first priority was to assess our understanding and knowledge of the way landscapes and catchments are functioning — if our understanding is not adequate, neither will be our models.

2.1.4. Monitoring and decision support systems

The North Australia Program recognizes that monitoring the state of soil, water and biological resources used or affected by the northern Australian beef industry is central to any adaptive management that maintains the integrity of the resource base. Similarly, decision support systems can be a useful tool for helping graziers with strategic and tactical decisions relating to managing their stock and properties so as not to degrade the vegetation and soil resources.

Different monitoring programs are already in place within Queensland, the Northern Territory and Western Australia but these, along with possible developments, are not considered in this review. Neither are any of the decision support systems available or under development. As with mathematical models, monitoring programs and decision support systems useful for improving management, can only be developed if the underlying understanding of landscape and catchment processes, and the effects of management, is sound. Consequently, since time was limiting, priority was given to a review of landscape and catchment processes.

2.1.5. Social and economic issues

The focus of subprogram 2 of NAP3 is to improve resource management. While technical understanding is clearly critical to such improvement, social and economic issues are also just as important. These have an overriding influence on the extent to which available information is taken up and put into practice. While this review recognizes their importance, it was not part of its scope to consider social and economic constraints to uptake and use of information, and how these constraints might be overcome. The review has focussed on current technical understanding.

2.2. Conceptual framework for the review

This review is essentially concerned with components of the hydrological cycle and closely associated nutrient cycles in northern Australian landscapes, how these have been modified through the introduction and management of extensive grazing systems, and the effects of these modifications on the land and water resources, including their biota. Of particular interest is whether the modifications have resulted in changes in landscape properties and processes which are undesirable from the perspective of continued productivity of our natural resources. Here the term 'productivity' is defined broadly and refers to the maintenance of the native biota as well as to production that has obvious and immediate economic benefit.

The prime focus of the review has been to identify changes in water, nutrient and sediment fluxes at different spatial scales (i.e., the amount of water, sediment and nutrient leaving different sized areas — a plot, hillslope, small catchment, etc) that are attributable to grazing and its interaction with climate and land management. While such information can provide insight into the effects of the grazing industry, on its own it is likely to be of little use in devising appropriate management strategies. Effective management requires an understanding of how a system (the land and its biota, both natural and introduced) is functioning — the processes operating, how they are influenced by land characteristics and management, and their inter-relationships. Three important factors must be taken into account in understanding system function — place, time-frame and spatial scale.

While the fundamental hydrological and geochemical processes operating are the same for all landscapes, their rates and exact nature vary with place, depending on the land characteristics (climate, geology, topography, soil and vegetation) and through time. Since processes vary in spatially and temporally, what happens over a large catchment (the Burdekin, for example) cannot be determined by observing what happens in one place and period of time within the catchment and then extrapolating this effect over the entire catchment, and over different time periods. We need to understand processes in different places (land types), over different time periods. We also need to understand how the processes operating in different places interact and how this interaction changes as the size of the area under consideration is increased.

Consequently, in addition to identifying changes in water, sediment and nutrient fluxes and their effect, this report has aimed to provide an overview of what is known of how the land and its biota function at different spatial scales, ranging from patch and small plot (square metres) through river basin and off-shore marine environment (thousands of square kilometres). What is known of changes in the functioning of large systems (for example large catchments) over long time periods, is reviewed where possible. Such knowledge is important in helping distinguish changes in large systems due to grazing from those which occur naturally. They also provide a context for any current changes which may be occurring. It would be useful to know, for example, if fluxes of sediment to the Great Barrier Reef Lagoon are currently greater than those in the recent past (last 2000 years or so). Such information may help to determine whether the estuarine and reef systems can withstand current sediment fluxes. Consideration is also given in this review to work that is attempting to identify likely changes in system function as a result of possible climate change. The history of past climates and associated changes on land may also be useful in this context, providing insights into possible changes in the future.

Given that the NAP3 program is concerned with the profitability and ecological sustainability of beef production in northern Australian, the review also considers the effects of on-site degradation and changes in processes, on the beef industry.

The conceptual framework, which forms the basis of the review, is illustrated in Table 1.1.

2.3. Form of the review

In order to assess the information available, the approach adopted was to pose and seek answers to a series of questions. These questions were:

- Are there any identified off-site degradation problems that can be clearly attributed to the northern Australian beef industry? The associated question is, are there potential off-site problems and what evidence is there that suggests these potential problems are likely to eventuate?

- What are the changed water and nutrient fluxes at local scale (up to tens of hectares) due to grazing management, clearing and pasture improvement, drought and fire?

- What do we know about processes and system function at the local scale, including any affects of changes in processes and functioning on cattle production?

Table 1.1. The framework used to consider the effects of grazing, burning and climate, tree clearing and pasture improvement

	PLOT	LANDSCAPE UNIT/SMALL CATCHMENT	RIVER BASIN/REGION (Including estuary)	LAND-SEA SYSTEM
SPECIFIC SYSTEM PROCESSES Hydrology			*Catchment outputs*	*Fate catchment outputs (eg. amount sediment/ nutrients reaching inner/outer reef)*
Erosion/sediment yield				
Nutrients				
SYSTEM FUNCTION Functioning in undisturbed condition				
Land use effects on system function — change in processes and degradation problems (including loss of biodiversity); susceptibility of land systems to degradation and potential for causing unwanted off-site effects				
System function under conditions of global change				

OTHER ISSUES WHICH DO NOT FIT INTO THE ABOVE MATRIX

- Management tools available (including monitoring)
- Effects of changes in system processes on profitability of the beef industry

- What are the changes in fluxes of water, sediments and nutrients that have occurred at regional and large catchment scales (up to thousands of square kilometres) and are these the result of the introduction of grazing or changed grazing practices?

- What work has been done in understanding system function at regional and large catchment scales and, in particular, do we know how changed sediment and nutrient fluxes at local scale affect fluxes at large scales?

- Do we know if fluxes of fresh water, nutrients and sediments at river mouths have changed or are changing, and whether they have the potential to alter the functioning and structure of estuarine and off-shore ecosystems?

- What information and management tools are currently available that could be used or developed to assist in managing grazing enterprises to ensure that productive potential of the land and water resources is maintained?

Component reviews were undertaken to help answer the above questions, and these reviews are provided in Section 2 (Reviews section) of this report. Section 1 of the report (titled Summary Report) contains a summary of the major findings of the component reviews (Chapters 2&3). It also discusses some of the on-site effects of overgrazing which are likely to impinge on animal production (Chapter 4) and briefly considers the importance of land resource survey and assessment (Chapter 5) in providing the necessary base for planning and evaluating land management. The final chapter, Chapter 6, assesses what research is needed and recommends priorities for NAP3 funding.

2.4. Overview versus review

Given the large geographic area involved, the amount of research completed and the number of groups involved in relevant work, this project was unable to provide a comprehensive review. Rather its aim has been to determine major areas of relevance and, within these areas, to identify past, current and proposed work. From this information an assessment has been made of where the significant deficiencies in understanding appear to be. Some work will have been overlooked in the process. At the workshop held in early August to allow comment on the draft review, some important gaps were identified and these have been rectified where possible. Even so, other gaps remain. This is not intentional and the author apologizes to those whose work has not been included. It should be noted that review of the international literature to provide a more complete understanding of the possible effects of grazing, was not part of this project.

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2. REAL AND PERCEIVED PROBLEMS

This chapter discusses the effects on water resources, both local and downstream, that can result from extensive grazing. It identifies the real and perceived threats associated with the northern Australian beef industry and, from the information available to this review, assesses their extent and the degree to which these problems can be clearly linked to the grazing industry. It also considers potential problems and the likelihood of their development. The focus is on the different *forms of degradation* of water resources that can be attributed to changes in water, sediment and nutrient movement in the landscape and, in the case of riparian zones, to the direct changes to habitat from cattle access or pasture management practices (clearing, burning and introduction of exotic species). The effect that grazing and grazing management have on land characteristics (soil and vegetation) and hence the processes involved in water, sediment and nutrient movement, is the focus of the next chapter, although the principles are discussed briefly here as part of identifying the forms of degradation that can result from grazing.

2.1. Potential effects of grazing in the context of the north Australian environment — principles

Processes involving the transfer of energy, water, and nutrients are fundamental within all landscapes and are involved in plant and animal production as well as soil and landscape development. The actual pathways and fluxes of energy, water, and nutrients within the landscape are determined by the characteristics of the landscape in question — its climate, geology and geomorphic history, topography, regolith and soil, and vegetation. For example, in flat terrain with deep sands, infiltration of rainfall is likely to be high and runoff very small to negligible. On the other hand, runoff of rainfall is likely to be relatively high on hilly terrain with poorly structured shallow loam soils developed on, say, sedimentary rocks.

The vast area covered by the north Australian grazing industry means that it incorporates an enormous variety of landscapes, and as a result natural processes are likely to vary considerably throughout the region. To begin with there are major differences in climatic regime, ranging from the humid wet/dry tropics with high summer rainfalls to the arid inland areas where annual rainfall is low but with high interannual variability. Major variation occurs between the more humid coastal catchments, in which water moves relatively quickly to the coast taking suspended and dissolved materials with it, and the flatter, more arid inland catchments. In these catchments, river flows tend to occur only after episodic rainfall events and much of the water infitrates into the river beds and floodplains or is evaporated before reaching the inland lakes in which the rivers terminate.

The introduction of any land use affects the natural environment and the processes within it, by altering characteristics of the vegetation and soils. For example, extensive grazing can affect species composition (through selective foraging), plant cover, plant root depth and soil surface condition. Management practices, such as burning or clearing and pasture improvement, also affect these vegetation and soil characteristics and, in addition, pasture improvement introduces non-native species to the landscape. Changing the soil and vegetation properties changes the rate at which various processes operate in the landscape. Where the change in processes leads to a decline in the productive capacity of land or water resources (including their capacity to maintain the native biota) we regard the processes as degradational and land and water degradation as having occurred. For example, reduction in plant cover exposes the soil to raindrop impact and this, combined with the associated loss of organic matter, can lead to surface sealing. Surface sealing reduces the infiltration of rainfall, and water which previously would have entered the soil, runs off and is unavailable for plant growth. This can lead to a further decline in plant production and, with continued grazing, plant cover.

Increased runoff can, through the additional energy associated with the increased volume of water, move sediment and attached nutrients, seeds and other organic matter. By this process, resources necessary for plant growth can be transported out of the local system and lost from the grazing land. Organic matter, sediment and nutrients transported to waterways will be variably transported through the drainage network to the catchment mouth. Changes in water, sediment and nutrient inputs to aquatic and marine environments have the potential to change the ecology of these systems. Such changes may be deleterious in that there is a general loss of biological diversity and unwanted species may flourish (eg, toxic blue-green algae or macroalgae on coral reefs). Users dependent on the continued healthy functioning of freshwater and marine ecosystems may be affected.

Management practices such as tree clearing and the introduction of leguminous pastures can have a different set of effects. Land cleared of trees and sown to exotic pastures often has a different water use regime from the natural vegetation that was replaced. In southern Australia, for example, replacing the natural forests and woodlands with introduced pastures has typically resulted in reduced interception and evopotranspiration which means that a greater volume of water is available to move through the soil profile and recharge groundwater. Recharge to groundwater will cause water tables to rise and eventually, to intersect the land surface causing increased waterlogging. Where the groundwater is saline or the rising water moves through regolith with a high salt content, salinisation of soils and surface water may result. The length of time for groundwaters to rise depends on the rate of recharge, on the permeability and water holding capacity of the regolith, and on the depth of the water table.

Leguminous pastures may also have an indirect effect on water movement. There is evidence that the leguminous pastures introduced to northern Australia are resulting in increased rates of soil acidification (Moody and Aitken 1997; Noble *et al.* in press) as is occuring under clover pastures in temperate grazing systems. Increased soil acidity will affect the growth and production of pasture plants both as a result of plant sensitivity to soil pH and as a result of increased manganese and aluminium availability and hence toxicity. Reduced plant growth and productivity will reduce plant cover, with similar affects to that caused by grazing. There will also be reduced uptake of nutrients, which will increase the potential for nutrient leaching to groundwaters.

The extent to which land processes are affected by grazing and grazing management depends on the extent of alteration produced by cattle and/or land management. For example, light grazing may exert relatively little affect as loss of foliage cover may not exceed either the threshold which leads to reduced plant vigour or that which results in increased runoff and erosion. The threshold to change also depends on factors such as climatic and soil conditions and whether the plant is already stressed, for example, through reduced water and nutrient availability. Thresholds to change are therefore variable in space and time. It is for this reason that management practices, such as stocking rates, need to be adjusted for different conditions.

Land characteristics also influence the extent to which land processes are affected by grazing and grazing management. Different land types have different inherent susceptibilities to degradation (Aldrick *et al.* 1988) so that, for example, grazing which results in similar levels of plant cover and soil exposure may result in different degrees of soil loss. Factors influencing the inherent susceptibility of the land to erosion include the topography (slope length, angle and shape), presence of a lag deposit, soil texture and structure and soil organic matter content.

Understanding the effects that cattle and grazing management can have in a particular landscape is consequently not a simple task. General principles can be determined but the specific effects will vary from landscape to landscape, and catchment to catchment. It is only possible in a review such as this to identify the possible effects of grazing and grazing management, rather than to provide specific information on the possible changes for different landscapes and for particular stocking rates. Also, in most instances, this review does not provide any indication of the extent to which degradational processes are occurring. As should be apparent from the discussion above, an extensive grazing enterprise need not necessarily be having adverse effects on land and water resources — whether it is or not depends on the appropriateness of the management practices adopted in relation to the land types present within the property.

2.2. Issues

Listed below are the *possible* changes in processes associated with hydrological and nutrient cycles that can be caused by grazing and grazing management, and the deleterious water quality effects that can result. All perceived problems have been listed, irrespective of whether they are actually occurring. It is the place of subsequent sections to assess the actual or potential occurrence of the problems. It should be noted that degradation of water resources only is considered since the main focus of the review was the downstream effects (including groundwater and ecological status of aquatic ecosystems) of grazing land management. It is recognized, however, that there will also be associated on-site degradation of the land resource.

- Increase in groundwater recharge as a result of clearing — an increase in recharge can cause increased waterlogging as a result of rising watertables, and a decline in plant productivity. In areas where salt is stored in the groundwater and/or regolith, there may be increased soil and water salinity. Increased water salinity can affect in-stream biota as well as use of water for domestic, industrial and agricultural purposes (including stock watering and irrigation).

- Increased inputs and leaching of nitrate associated with pasture improvement — nitrate contamination of waterbodies and increased soil acidification; the effects of increased soil acidification are described above.

- Increased fluxes of sediments to waterways and standing waterbodies — sediments may reduce the utility of dams and water storages, including property dams; increased sedimentation is known to affect the ecology of some systems, for example, estuarine seagrass beds.

- Increased fluxes of nutrients to waterways and standing waterbodies — the concern is that inputs of nitrogen or phosphorous may stimulate algal blooms in inland waterways and off-shore, and may also affect the species balance of communities, for example favouring macrophytic algal growth to the detriment of corals.

In addition to the deleterious effects on aquatic environments brought about by increased sediment and nutrient inputs, cattle can also cause direct changes to riparian and wetland flora through grazing and trampling. This has consequent implications for the fauna dependent on the riparian vegetation. Change in vegetation may also have indirect effects on stream and wetland ecology through changed energy fluxes (light, temperature), and organic and mineral nutrient inputs. Indirect effects of cattle trampling and wallowing result from compaction of the soil which may inhibit plant regeneration.

A further potential effect of cattle on aquatic environments is the increased input of microbial pathogens and nutrients from cattle excreta. There appears to have been little investigation of such inputs and the probability of them causing a decline in water quality. Consequently they are not considered further in this section of the report.

The provision of artificial watering points is another aspect of grazing land management that affects the hydrology of landscapes in northern Australia. The water used comes both from stored surface runoff after rain and from groundwater, either under pressure from confined aquifer systems (artesian bores) or pumped from unconfined aquifers. Landsberg *et al.* (1997) report that artificial watering points are now so numerous in the arid and semi-arid rangelands that there is rarely more than 10 km between them. These artificial watering points have two potential effects. One is the effect of removal of water from the groundwater system, the other is the effect on the land and regional biota.

2.3. Salinity

2.3.1. Summary

Extensive areas of dryland salinity exist in southern Australia as a result of altering the water regime by tree clearing and establishing more shallowly rooting, often annual, pasture and crop species. To date, dryland salinity in northern Australia has not developed to anywhere near the same extent as in the south. There are differing views as to whether this is purely because tree clearing has not yet occurred on the same scale in the north, or whether it is because the potential for dryland salinization is much lower.

Surveys and hydrological studies in Queensland and the Northern Territory indicate that the conditions necessary for salinization, that is saline regolith and/or groundwater, and potential for an increase in water movement beyond the root zone following clearing, are present in at least some areas. Evidence for increased water movement below the root zone following clearing comes from modelling the water balance for soils near Charters Towers (Williams *et al.* 1997). These simulations have shown that recharge in the seasonally wet/dry tropics is likely to be highly episodic. The potential for increased recharge is also likely to be highly variable for the different climatic regimes and landscapes across northern Australia. No relevant literature on the potential for salinization was found for north-west Western Australia.

Assessments to determine the susceptibility of land to salinization, identified during this review, include that for the Northern Territory (Tickell 1994), the Dalrymple Shire in Queensland (Bui 1995) and the study in the Ipswich and Kingaroy areas of Queensland (Searle and Baillie, in prep). These assessments are regarded as providing a first approximation only and further refinement in the assessment of areas susceptible to salinization is necessary to help develop land clearing guidelines. Not all areas with saline regolith appear to be susceptible to salting. Studies at the Brigalow Research Station in Queensland, for example, found little difference in recharge between cleared and uncleared catchments (Lawrence and Thorburn 1989) and this was attributed to the generally relatively shallow rooting depth of brigalow (*Acacia harpophylla*).

Current work being undertaken in the Balfes Creek catchment suggests that paleodrainage lines are considered possible major sites of stored salts, as in SW Western Australia. The work in the Northern Territory identified higher than average salt storage in the lateritised Cretaceous claystone on the Barkly Tablelands and Sturt Plateau. Further investigation of relationships between salt storage and particular landscapes (defined by climate, geology and geomorphic history) would seem warranted. Hydrological work (including use of simulation models) is necessary to determine effects of clearing on rates of water movement below the depth of plant rooting and actual groundwater recharge, in landscapes with salt stores.

The risk of dryland salinity occurring in the north depends not only on the potential for salinization inherent in the land, but also on the extent to which changes in the vegetation which affect components of the water balance, are likely to occur. Walker and Weston (1990) estimated there to be about 22.1 m ha which is easily available for development to sown pastures. They estimated development of 42.5% of this potential had occurred, with 4.4 m ha with sown grasses and 5.0 m ha with naturalized pasture. The extent of sown grass and legume pastures in Queensland in 1985 is shown in Figure 1.

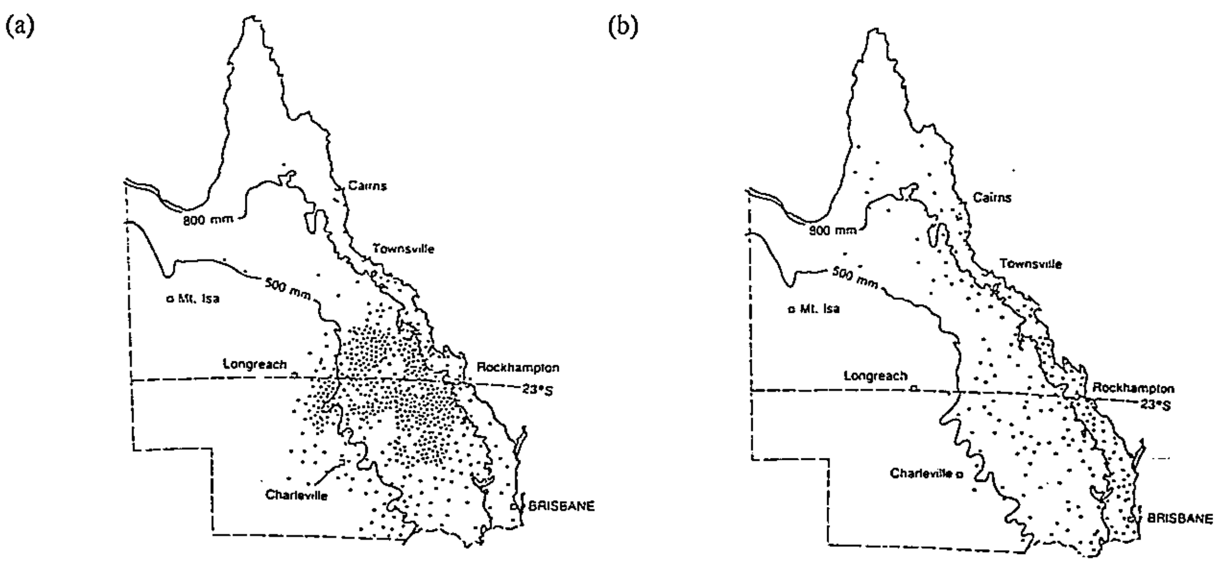

Figure 1. Distribution of sown grass pastures (a) and of pastures sown with legumes (b) in Queensland in 1984-85. Each dot represents 5 000 ha. (From Walker and Weston 1990)

It was not possible to obtain an accurate assessment of the amount of clearing that has already taken place although Figure 2 provides an estimate of the amount of clearing up till 1983. The current State-wide Land use And Tree clearing Study (SLATS) is mapping the rate of tree clearing from 1991-1995 at 1: 250 000 scale, using Landsat images with 30 m resolution. There are now clearing controls in place and permits to clear land are required. Guidelines have been developed for clearing land with indicators of possible salinity and these are being upgraded as more specific information on the susceptibility of land to salinization becomes available.

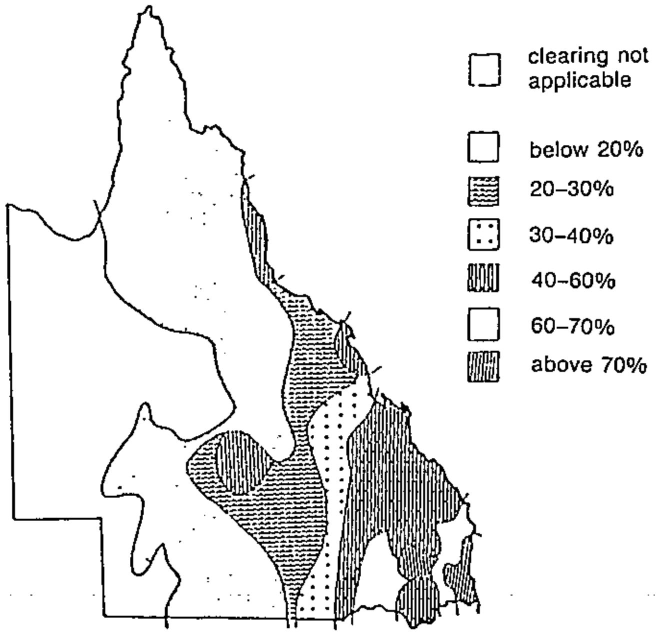

Figure 2. The extent of clearing of open forests and woodlands in Queensland up to 1983. (From Walker and Weston 1990, derived from Burrows *et al.* 1988).

2.3.2. Current relevant projects

(Details of some projects given in Reviews 3&4)

Title and contact	State	Catchment/region	Issue	Status
Estimation of sustainable groundwater pumping rates Derek Eamus	NT	Near Darwin (1600 mm rainfall)	Water balance including groundwater recharge	Current; intention of extending work to other land types
Groundwater resources of Balfes Creek Catchment Jason Keys	QLD	Balfes Creek (Burdekin National Dryland Salinity Program focus catchment)	Development of a hydrological map of Balfes Ck catchment and interpretation of groundwater movement.	Current
Paddock scale guidelines for salinity management in the Balfes Ck catchment Ian Gordon	QLD	Balfes Creek, Burdekin catchment	Integrating point and catchment scale models to develop vegetation management strategies which will minimize salinity risk in the Balfes Ck catchment.	Just starting
Evaporation from trees and regrowth Steve Kalma	QLD	Balfes Creek, Burdekin catchment	Measure transpiration in established old growth and regrowth vegetation.	
Upper Alice River catchment Project George Bourne and Michael Herring	QLD	Upper Alice River, Barcoo catchmen (representative of the Desert Uplands)	Assessment of areas potentially at risk from dryland salinity for given tree clearing options	

Salinity hazard mapping in SE Queensland Ross Searle and Justine Baillie	QLD	Kingaroy and Ipswich regions	Pilot study of use of landscape characteristics to map salinity hazard at 1: 250 000 scale	12 month trial; in the final report stage
Sustainability of Stylosanthes *based pasture systems in northern Australia (subproject 1)* Andrew Noble	QLD, one site in NT	Northern and central Queensland; Manbulloo, NT	While nitrate leaching is the focus, this project will provide comparative water balances for soils under *Stylosanthes* and native pasture.	1997-2000
Sustainable groundwater use in northwest NSW and southern Queensland Jim Kellet	QLD and NSW	Southern Queensland catchments overlying the Great Artesian Basin (Condamine, Culgoa-Barwon)	Recharge studies to provide improved information for groundwater models of the GAB	Proposed

2.4. Soil acidification and nitrate contamination of groundwater

2.4.1. Summary

Stylosanthes pastures (*S. scabra* and *S. hamata*) have been introduced to northern Australian grasslands to improve their quality and dietary value in the dry season. Legume pastures in southern Australia have been found to be associated with accelerated soil acidification, a problem which is now being investigated in the north. Preliminary studies have measured increased rates of acidification under *Stylosanthes* pastures and increased rates of nitrate leaching have been suggested as a possible cause (Noble *et al.* in press). A project, *Sustainability of* Stylosanthes *based pasture systems in northern Australia: managing soil acidity*, has recently been initiated, funded by the MRC, to investigate the long-term sustainability of legume based pasture systems in the semi-arid tropics. Its focus is on quantifying the inherent fertility status of various pasture production systems through the establishment of long-term monitoring sites at various localities.

The possibility of increased rates of nitrate leaching associated with *Stylosanthes* pastures raises the possibility of nitrate contamination of groundwater. The potential for nitrate contamination of groundwaters seems to occur wherever nitrate can accumulate in soil prior to the onset of rains sufficient to leach the nitrate below plant roots and the activity of any denitrification. There have been few investigations of nitrate dynamics under northern Australian legume pastures so the potential for these systems to cause groundwater contamination, is unknown although not particularly likely (Andrew Noble, pers. comm). The current project *Sustainability of* Stylosanthes *based pasture systems in northern Australia: managing soil acidity* should provide data that will give a better indication of the probability of this process. Relatively high nitrate concentrations are known to occur in some arid zone groundwaters. In at least one case, this has been attributed to leaching of nitrate from nitrogen fixation by cyanobacteria and in termite mounds (Barnes 1992).

2.4.2. Current relevant projects

Title and contact	State	Catchment/region	Relevant issue	Status
Soil acidification and fertility decline				
Sustainability of Stylosanthes *based pasture systems in northern Australia: managing soil acidity* Andrew Noble	QLD, one site in NT	Northern and central Queensland; Manbulloo, NT	Monitoring soil fertility and water changes; predicting risk of acidification; development of sustainable legume-based pasture systems; communication of results.	1997-2000

Nitrate contamination of groundwater

Sustainability of Stylosanthes *based pasture systems in northern Australia: managing soil acidity (Subproject 3.4)* Andrew Noble	QLD	"Lansdown", Burdekin Catchment	Quantifying mineral nitrate dynamics under a *Stylosanthes* dominant pasture	1997-2000

2.5. Effects of grazing on wetlands and riparian habitats

(Summary from the review: "*The impacts of the northern Australian grazing industry on wetlands and riparian habitats*" by Michael Douglas and Alison Pouliot).

In this report, riparian areas are "that part of the landscape which exerts a direct influence on stream channels or lake margins and on water and aquatic ecosystems contained within them" (Bunn and Price 1993). The term wetland broadly follows the definition used by the Ramsar Convention: "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, including areas of marine water depth of which at low tide does not exceed six meters" (Davis 1994). The focus, however, is on natural freshwater wetlands, which, following the definition above, also includes streams and waterways. Generally the literature on the effects of grazing is based on observation and/or highlights potential problems; there is an extreme paucity of specific information.

Riparian habitats and wetlands tend to be areas of high utilization by cattle. Firstly they are close to, or provide water. Secondly, riparian areas often have higher fertility with the result that cattle have a greater preference for riparian pastures. The potential for cattle to affect the biological diversity of these areas is increased by the fact that in the dry season, and particularly during droughts, riparian habitats and wetlands are not only increasingly attractive to cattle but can act as refugia for native species.

As well as the direct of effects of cattle utization of riparian habitats and wetlands, management practices associated with the grazing industry, such as burning and the introduction of ponded pastures, can also have a marked affect on the native biota.

2.5.1. Riparian biodiversity

The direct effects of grazing on riparian vegetation are clearly visible and involve damage to the vegetation and loss of cover, and trampling and compaction of the soil and stream banks. As a result weed invasion can occur and the regeneration of native plants can be limited or prevented. Despite the visible signs, there has been very little work quantifying the areal extent of damage or the loss of communities or species. With respect to fauna, a little more is known although there is still a dearth of information. No studies were identified, for example, that have investigated the response of invertebrates to grazing. There also appears to be no report of decline in specific mammal populations in northern Australia although various studies have shown that mammals utilizing riparian areas are likely to be particularly susceptible to grazing. In central Australia, grazing has been implicated in the decline and extinction of several mammal species. Some amphibians and reptiles, for example freshwater turtles, have also been found to be highly dependent on riparian zones and hence susceptible to the effects of grazing in these areas.

The most well documented effects of grazing on bird populations are those on the Purple-crowned Fairy-wren (now listed as vulnerable, Garnett 1992) and the White-browed Robin (Smith and Johnstone 1977; Boekel 1980; Rowley 1988; Woinarski 1992; Rowley 1993). These insectivorous species have disappeared from riparian grasslands and fringing *Pandanus* from many areas in the Kimberley, following the loss of this vegetation through overgrazing. Finches of tropical woodland in the NT have also declined with increasing grazing pressure (Tidemann 1990) and, since riparian zones are important for granivorous and nectivorous birds, they are possibly implicated. In a review of the conservation status of arid zone bird species, overgrazing was considered the principle cause for a decline in species, with species having a preference for grassy riparian habitats and chenopod shrublands being disproportionately affected (Reid and Fleming 1992).

2.5.2. Wetland biodiversity

As for riparian habitats, there has been little investigation of the effects of grazing on wetland vegetation, even though northern wetlands may be more susceptible to grazing pressure than those in southern Australia due to seasonal drying giving cattle greater access. Some work, however, has shown that lignum (*Muehlenbeckia cunninghammi*) and species such as wild rice (*Oryza* spp.), which are important for wildfowl, have declined or disappeared from parts of the black soil lakes of the Barkly and Sturt drainages where grazing has occurred (Jaensch *et al.* 1995).

In-stream fauna are most likely to be indirectly affected by grazing. Trampling of stream beds and increased sediment and silt in rivers from erosion and slumping of banks, can totally destroy in-stream habitat. Also, since riparian vegetation affects various inputs to streams (organic material, light, temperature), change to riparian vegetation can markedly affect in-stream conditions. Despite the vulnerability of aquatic invertebrates and fish, little is known of what changes have occurred to populations of these animals as a result of habitat changes. With respect to invertebrates, some correlations have been made between reductions in diversity and abundance over time, with catchment disturbance, including increased stream-bank degradation and turbidity due to grazing. The only known investigation on the effect of grazing on fish, is a study of red-finned blue-eye from the Edgbaston Spring complex in central Queensland. This work suggests disappearance of the fish from two springs could be due to habitat destruction caused by stock trampling and by excavation of the springs to increase water storage for stock watering.

2.5.3. Weeds

Tropical wetlands and riparian habitats are particularly susceptible to weed invasion. Of the top 18 environmental weeds, 14 occur in wetlands or riparian areas in northern Australia and 8 are clearly linked to aspects of cattle grazing (Humphries *et al.* 1991). Grazing may influence weed establishment in several ways. Trampling and erosion may make riparian and wetland areas more susceptible to weed invasion, and selective grazing may prevent regeneration of native species, facilitating the establishment of weeds. An example is invasion of Rubber Vine (*Cryptostegia grandiflora*), a species known to choke riparian vegetation, thereby removing important bird habitat. Many species such as Parkinsonia (*Parkinsonia aculeata*), Rubber Vine, Prickly Acacia (*Acacia nilotica*), Mesquite (*Prosopis* spp.) and possibly Buffel grass (*Cenchrus ciliaris*), are spread by cattle through their faeces or attached to their skin.

Pastoral managers may actively introduce and spread exotic species in wetland and riparian areas in an effort to reduce land degradation or to provide shade or fodder for stock. For example, Mesquite, originally introduced to provide shade and fodder for cattle and as a garden ornamental, now forms dense stands around some watercourses. Dense riparian stands of Mesquite and Parkinsonia can inhibit wildlife movement and access, and are a cause of concern for wetlands on the Barkly Tablelands and in central Queensland. Similarly Buffel grass was introduced to the NT and the Kimberley as a pasture species and to ameliorate erosion from overgrazing and is now well established in riparian and other mesic habitats throughout the arid and semi-arid zone. The environmental affects of many of these weed species are virtually unknown.

2.5.4. Ponded pastures

Ponded pastures, where water is retained in natural or artificial wetlands through the constructed earth banks and levees, are most widespread in central Queensland where about 22,000 ha have been ponded (Coffey 1991). However, proposals to develop ponded pastures in southern Cape York Peninsula and introduce pasture species with known potential to become serious weeds (Clarkson 1991), are a major concern. Species introduced to ponded areas which are on the list of nationally important weeds, include Para grass (*Brachiaria mutica*), Aleman grass (*Echinochloa polystachya*) and Hymenachne (*Hymenachne amplexicaulis*). Species used in ponded pastures have also been observed to spread and displace native vegetation that is of importance to wetland birds. For example, Fisk (1991) has noted that as Para grass becomes established in some areas, fauna dependent on vegetation that grows along wetland margins, such as brolgas which feed on Bulkuru bulbs, suffer a serious decline in food resources.

Other environmental concerns associated with ponded pastures include:
- reduction in diversity and change in hydrology of natural wetlands which will affect habitat value;
- effect on passage of migratory fish (e.g. migration of juvenile barramundi);
- interference with the role of coastal plains as nursery areas and refuges for juvenile stages of many estuarine species;
- reduction in freshwater runoff to estuaries and changes in tidal flows and freshwater/saltwater interactions;
- potential for diversion of freshwater with consequent ill effects on the system from which water was taken;
- development of mosquito breeding areas with ineffective natural controls; and
- development of habitat favouring some native wildlife species, allowing populations to reach nuisance levels.

Others have highlighted the beneficial affects of grazing, and the role of cattle in keeping the weeds in check once these pastures have been established. The need for on-going grazing, however, can also be regarded as negative aspect of ponded pastures as it highlights the potential of these areas to cause problems should management be reduced for any reason.

2.5.5. Fire management

Relatively little is known about the affect of fire regimes on riparian vegetation. The invasion of riparian areas by grasses such as buffel grass which can increase the intensity and extent of fires, has possibly changed the relationship between fire and riparian vegetation and affected the habitat value of riparian areas. In contrast, grazing of riparian areas in Queensland is thought to have kept fuel loads at low levels, reducing the frequency of fire and thus helping the establishment of rubber vine. Experiments with fire regimes (no burn compared with late-dry season burning) in Kakadu National Park showed a decrease in richness of vines and woody species with burning, and an increase in richness of aquatic macrophytes and invertebrates (Douglas and Lake 1996).

2.5.6. Repair of degradation

Restoration of riparian habitat and wetlands following damage by grazing, seems to be a neglected area of research. Rehabilitation of degraded areas requires a knowledge of the ecosystem and its processes prior to disturbance (Ludwig and Tongway 1996) and for many riparian and wetland areas such knowledge is not available. In addition, successful and cost-effective re-establishment of vegetation requires a knowledge of the regeneration ecology of the species involved. For many northern Australian species, such information is limited. For example, factors limiting the regeneration of Eucalyptus miniata, one of the widespread trees of northern Australian savannas, were only recently identified (Setterfield *et al.* 1993).

2.5.7. Unpublished and current projects

Table 1 lists relevant current, unpublished projects, but excludes articles based only on reviews of literature.

2.5.8. Conclusions

This report is unable to provide an adequate assessment of the effects of grazing and pasture management on riparian areas and wetlands because of the extreme dearth of quantitative data, as distinct from anecdotal and observational reports. Even so, sufficient information is available from both sources to clearly indicate that grazing and pasture management can have a pronounced effect on wetland and riparian communities, leading to changes in, or in some cases loss of, floral and faunal populations. If declines in natural habitat and wildlife populations are to be halted, there is an essential need to determine the levels of grazing

Table 1. Summary table of projects listed by state, catchment, and issues.

Contact	State	Catchment/Region	Issue	Status	Organisation	Division
Douglas	NT	Alligator Rivers Region	Fire and aquatic vegetation	Current	NTU	CTWM
Douglas	NT	Alligator Rivers Region	Fire and macroinvertebrates	Current	NTU	CTWM
Douglas	NT	Alligator Rivers Region	Fire and riparian vegetation	Current	NTU	CTWM
Stowar *et al.*	NT	Alligator Rivers Region	Fish and erosion	Completed	ERISS	
Stowar *et al.*	NT	Alligator Rivers Region	Macroinvertebrates and erosion	Completed	ERISS	
Douglas *et al.*	NT	Alligator Rivers Region	Para grass	Proposed	NTU	CTWM
Jaensch	NT	Barkly Tablelands	Birds in Riparian	Completed	PWCNT	
Reid	NT	Central Australia	Birds in Riparian	Completed	CSIRO	
Whitehead	NT	Mary River	Grazing of wetland vegetation	Current	PWCNT	
Woinarski	NT	Micthell Grasslands	Birds in Riparian	Proposed	PWCNT	CRCSDTS
Woinarski	NT	Various	Birds in Riparian	Current	PWCNT	CRCSDTS
MRHI	NT	Various	Macroinvertebrates	Current	DLPE	
Dostine	NT	Various	Macroinvertebrates in Riparian	Current	PWCNT	CRCSDTS
Cheal	NT	Various	Plants in Riparian	Current	PWCNT	CRCSDTS
Haytesbury	NT	Victoria River District	Rehabilitation	Current		
Boekel	NT	VRD	Birds in Riparian	Completed	?	
Douglas		Various			NTU	CRCSDTS
Bunn and Davies	QLD	Bamboo Creek, Innisfail	Para grass	Completed	GU	CCISR
Arthington	QLD	Brisbane River	Macroinvertebrates	Completed	GU	CCISR
Arthington	QLD	Brisbane River	Water quality	Completed	GU	CCISR
Brown	QLD	Burdekin	Landscape restoration	?	CSIRO	CRCSDTS
Lucaks	QLD	Burdekin	Grazing of riparian vegetation	Completed	JCU	ACTFR
Lukacs	QLD	Burdekin	Grazing of wetland vegetation	Completed	JCU	ACTFR
Lucaks	QLD	Burdekin	Water quality	Completed	JCU	ACTFR
Duivenvorden	QLD	Central Fitzroy	Macroinvertebrates	Current	CQU	CLWR
Duivenvorden	QLD	Central Fitzroy	Algae	Current	CQU	CLWR
Noble	QLD	Central Fitzroy	Water quality	Current	QDNR	CQU
Bunn and Davies	QLD	Cooper Creek	Algae trampling	Current	JCU/UWA	CCISR
Lorimer	QLD	Desert Uplands	Rehabilitation	Current	QDEH	
Rowley	QLD	Gulf	Birds in Riparian	Completed	CSIRO	
Williams	QLD	Townsville	Hymenachne	Current	QDEH	
Pearson	QLD	Townsville	Macroinvertebrates	Completed	JCU	ACTFR
Williams	QLD	Townsville	Para grass	Current	QDEH	QNPWS
Brown	QLD	Townsville	Riparian biota/water quality	Current	CSIRO	TA
Pearson	QLD	Townsville	Water quality	Completed	JCU	ACTFR
MRHI	QLD	Various	Macroinvertebrates	Current	QDPI	
Rowley	WA	Kimberley,	Birds in Riparian	Completed	CSIRO	
Woinarski	WA	Kimberley, Purnululu	Birds in Riparian	Completed	PWCNT	
Pettit	WA	Ord River	Riparian vegetation	Current	ECU	
Davies	WA	Pilbara	Water quality	Completed	UWA	
MRHI	WA	Various	Macroinvertebrates	Current	WAWA	

ACTFR	Australian Centre for Tropical Freshwater Research	**GU**	Griffith University
		JCU	James Cook University
CCISR	Centre for Catchment and Instream Research	**NTU**	Northern Territory University
CCNT	Conservation Commmission of the Northern Territory	**PWCNT**	Parks and Wildlife Commission, NT
CQU	Central Queensland University	**QDPI**	Queensland Department of Primary Industry
CSIRO	Commonwealth Scientific and Industrial Research Organisation	**QNPWS**	Queensland National Parks and Wildlife Service
CTWM	Centre for Tropical Wetlands Management	**TA**	Tropical Agriculture
DLPE	Department of Lands Planning and Environment	**UWA**	University of Western Australia
ECU	Edith Cowan University	**WAWA**	Western Australian Water Authority
ERISS	Environmental Research Institute of the Supervising Scientist	**WRD**	Water Resources Division

compatible with maintaining the natural biological diversity of different wetlands and riparian areas. This necessitates base data on our wetland and riparian flora and fauna; such data are relatively sparse in northern Australian landscapes.

Given the observed preference of grazing animals for riparian areas in many environments, strategies for managing grazing in riparian areas also need to be developed. Such a need was also identified as important in the National Wetlands R&D Scoping Review (Bunn 1996). Fencing off riparian areas is one possibility that has been found, in one instance at least, to be financially neutral, with benefits offsetting costs. It is recognized, however, that this solution may not be appropriate for large areas of the rangelands. In some situations, total exclusion of grazing may not be necessary but more needs to be known about the sensitivity of different riparian areas to grazing and the capacity of local flora to regenerate in the presence of, or after, grazing activity.

In deriving information on grazing pressures compatible with maintaining the natural riparian flora and fauna, management within the whole catchment, and not just the riparian and wetland areas, must be considered, as processes in the whole catchment have the capacity to impinge on riparian zones and wetlands. Investigations also need to include the seasonal variability in the wet/dry tropics and the considerable interannual variation in rainfall. Rainfall pattern determines the movement of both stock and native biota as well as the degree of their dependence on wetland and riparian areas. It is essential to obtain information during critical dry periods when these habitats act as refugia for native fauna.

Methods for restoring or rehabilitating riparian areas and wetlands are very poorly understood, particularly where heavy weed invasions have occurred . While many Landcare and other restorative programmes are underway, more research is needed to provide a sound scientific basis for these schemes and to ensure that large scale channel instability does not occur if dense infestations are removed. Monitoring and assessment of the success of these programmes should also be a priority.

The problems associated with eradicating weed infestations raises the issue of the introduction of ponded pasture species, known to be problem weeds, to new areas. While there is no doubt that ponded pastures are profitable additions to grazing enterprises, it is also clear that weed invasions cost the community extremely large sums of money in eradication programs. Clearly it is essential not to let the problem develop in the first instance. At the *Beef Production from Ponded Pastures* workshop held in 1993 (Pittaway *et al.* 1996), the potential seriousness of expansion of ponded pastures was pointed out while it was acknowledged that minimal envirionmental research has been carried out and that we do not yet have the information to determine how likely are the undesirable effects. Research is required to help resolve some of the issues and the recommendations of Lukacs (1996) are noted here. Lukacs recommended that research associated with use of potentially invasive exotic grasses should include: "an international biogeographic survey to quantify existing populations and their ecological parameters; the development of predictive models to assess potential invasive spread; monitoring of selected ponded pastures; autecological studies of pasture species utilised; and the development of competition based experimentation." He also suggested investigation of the use of native species in ponded pastures.

2.6. Eutrophication and algal blooms in freshwater systems

2.6.1. Summary

(From Review 1: "Eutrophication and algal blooms in freshwater systems of northern Australia" by Terry Donnelly)

Nearly all standing waterbodies in Queensland are susceptible to blue-green algal (cyanobacterial) blooms (Gary Jones, National Algal Manager, *pers. comm.*). The recognition of the susceptibility of Queensland freshwater systems seems only to have developed in the last five years or so as the result of an increased monitoring and recording program. In contrast, freshwater systems in the NT and the NW of Western Australia seem to have low nutrient status and low susceptibility to bloom development, at least under present conditions, with very few cyanobacterial blooms having been recorded.

The relationship between algal bloom development in Queensland and grazing in pastoral lands is unclear. This is mainly because our understanding of the mechanisms involved in algal bloom development in

Australia is still far from complete. It is now thought that the anthropogenic point source inputs of phosphorus, which can give rise to eutrophication problems in the northern hemisphere, are unlikely to be major contributors to nutrient concentrations in Australian freshwater systems, other than locally. This is attributed to the large in-stream sediment stores which, under the anoxic conditions following stratification of a waterbody, can release large amounts of phosphorus, and also to the capacity of these sediments to remove added soluble phosphorus from the water column. Other factors implicated in controlling bloom development in Australian freshwater systems are the usually high turbidities, high temperatures, low river flows (particularly following river impoundment), usually high clay contents of sediments, and the activity of sulphate-reducing bacteria. The role of sulphate in the release of phosphate from sediments has been confirmed by Chiswell *et al.* (1995). In Australian systems, sulphate is usually derived either from the influx of saline groundwaters or from the use of agricultural fertilizers, including superphosphate.

Since the large algal bloom on the Darling-Barwon River in 1991, change in water phosphorus concentration to levels above a limiting threshold, has been regarded as a major stimulant to bloom development and much work has focussed on the processes and mechanisms whereby this change has been produced. It is becoming apparent from current and recently completed work, that nitrogen may be playing a larger role in the development of blooms than currently thought (Richard Davis, coordinator National Eutrophication Management Program, pers. comm). A project in the Fitzroy catchment currently being developed for the National Eutrophication Management Program will provide an indication of whether nitrogen plays a role in the growth of cyanobacteria in rivers and storages, and about the role of denitrification (Harris 1997). High river turbidities are also being increasingly regarded as limiting bloom development. One corollary of this is that attempts to improve water quality by reducing turbidity, may have the effect of increasing blooms if the other factors that control algal growth (particularly nutrients) are not limiting (Richard Davis, pers. comm).

The reports of cyanobacterial blooms in Queensland catchments with little disturbance, indicates that blooms can occur naturally. However, the increased storage of water and any increased nutrient (N & P) and sulphate input can exacerbate an existing problem, although the exact extent to which this is the case cannot be defined. Certainly reducing the frequency of blooms must involve ensuring the influx of sediments and nutrients to waterways is reduced, and in catchments where pasture improvement is occurring, that fertilizer inputs to waterways do not occur. There is a need to ensure that sulphate concentrations in waterways do not exceed their pre-European values. Given that blooms are toxic to animals as well as humans, such reductions are not only to prevent downstream effects for other users but are in the graziers' own immediate interest. The potential for toxins to accumulate in animals is still being investigated. It is an important issue with regard to the purity of our agricultural products.

The lack of cyanobacterial blooms in the NT and north-west of Western Australia is interesting, particularly given their occurrence in Queensland, and an investigation of the reasons may provide insight into the mechanisms causing bloom development in other parts of Australia. Possible causes for the difference between freshwater systems in the NT and north-west of Western Australia, and those in other states, include:

- generally lower fertility (P status) of the NT and northern WA soils;
- the seasonal wet/dry climate which provides both flushing and mixing of water over the wet season, and an extended dry period — there is evidence to suggest that drying of sediment bound phosphorus reduces its bioavailability;
- the presence of good macrophytic growth which both filters the input of phosphate as well as removes phosphate from the water column;
- cattle numbers and cattle access to streams being below the critical thresholds needed to create a bloom problem; and
- monitoring and awareness not being sufficient, although this is considered unlikely.

While the precise role of the northern grazing industry in the development of algal blooms will be difficult to define until the mechanisms of bloom development are better understood, it is clear that increased nutrient inputs associated with increased runoff (see next chapter) can only be exacerbating any problem that exists naturally. It is also worth noting that studies referred to in the review by Douglas (this report) indicate that cattle access to streams resulted in locally elevated nutrient levels leading to eutrophication (Butler and Faithful 1991). Also, in the Northern Territory, one algal bloom that has been recorded was associated with cattle access to a billabong.

2. 6.2. Relevant current and proposed projects in the National Eutrophication Management Program

(Details of projects given in Review 1)

Title	Contact	State
Modelling nutrient release from sediments and lowland river storages	Prof. Barry Hart	Generic
The interaction of physics, biology and nutrient regimes on the initiation and development of algal blooms	Dr Susan Blackburn	Generic
Retrospective study of nutrient variations in some riverine systems	Dr Andy Herczeg	NSW, Qld, SA, Vic, WA
Movement of phosphorus through soils	Dr Jim Cox	SA
Measurement and treatment of phosphorus and carbon subsoil movement	Dr Jim Cox	SA
Effects of episodic events on aquatic ecology in tropical and subtropical areas	Project still in scoping phase	Fitzroy, Qld
Mamagement strategies for control of cyanobacterial blooms in the Fitzroy River barrage	Dr Miriam Bormans	Fitzroy, Qld
Whole lake biomanipulation for the reduction of nuisance micro-algae	Dr Vlad Matveev	Fitzroy, Qld

2.7. Sedimentation of waterways, dams and the marine environment

Heavy grazing pressures can have a definite effect on runoff and erosion, increasing the loss of water, soil and nutrients wherever loss of cover exceeds critical thresholds. This is the result of a number of changes in soil properties and processes (see Chapter 3). Water and dissolved nutrients tend to flow directly from the system although nutrient cycling processes within waterways and the sorption, release and transformation processes cannot be ignored in considering the effect of these nutrient inputs on biological processes. The movement of sediment is complicated by the fact that larger particle sizes tend to be deposited in channels or on floodplains downstream so that not all sediment eroded from a paddock will be immediately transported to the catchment mouth. The length of time that such sediment is stored within a catchment is unknown.

2.7.1. Effect of sedimentation on stream, estuarine and marine environments

While there is no doubt that overgrazing of pastures has increased the mobilization of sediment, with increases in sheet, gully and channel erosion, where this sediment is being deposited, the effects of deposition and the effects of increased river sediment loads/turbidity are not clear. That there are effects is beyond doubt but this project was unable to identify any specific documented cases of effects on apart from the studies on changes in stream invertebrate populations, identified in the review by Michael Douglas, and reports of dieback of seagrass beds associated with flooding and sediment deposition. Seagrass losses in Moreton Bay in the 1970s were attributed to increased sedimentation and a rise in substrate levels; loss of an estimated 902 km^2 of seagrass in Hervey Bay in 1992-3 is thought to have been due to high turbidities resulting from flooding of the Mary and Burrum Rivers.

The lack of documented deleterious effects could be due to a number of factors, including the complexity of natural systems that results in some inputs not having immediate effects, and insufficient base information. For example, coastal seagrass communities are known to be susceptible to smothering by sediments but seagrass communities along 6500 km of the coastline of northern Australia have not been surveyed (Poiner and Peterken 1995).

2.7.2. Sediment deposition in dams and lakes

Sediment tracing work has been undertaken for Lake Argyle and this showed most sediment was derived from subsoils rather than topsoils. That is gullies and stream channels close to the Lake were identified as the major source of Lake sediments. It is difficult to define what proportion of this sediment input is attributable to grazing, but given that gully development in this catchment is considered the result of grazing, it can be assumed that grazing has increased sediment inputs to the Lake. Also, since Lake Argyle seems to have a very high sediment trap efficiency (reported by Wasson *et al.* 1994 at >99%), very fine sediments in surface runoff would be contributing to sediments within the Lake. Plot studies (Review 4) have shown grazing can increase the amount of fine sediment in suspended loads.

This review was unable to find data that indicate where sediment lost by sheet erosion of grazing land is deposited. Sedimentation of farm water storages shows that these are sites affected by local soil loss, but as these are often located on waterways, it is not always possible to determine whether the sediment is from sheet erosion or from erosion of channels and gullies. Similarly, for storages on large waterways in downstream locations, sources of sediment have generally not been identified.

2.7.3. Current research

Individual/organization	Area of research
Australian Geological Survey Organization David Heggie	Eutrophication in estuarine environments
Australian Institute of Marine Science (incomplete listing of relevant projects)	
Dan Alongi	Human impacts on coastal food webs and nutrient cycles
Gregg Brunskill	Environmental history from sediments
Barry Clough	Rivers and mangroves
Peter Isdale	Environmental history from corals
Laurence McCook	Algae as indicators of reef degradation.
CSIRO Division of Marine Research	Projects not determined
Great Barrier Reef Marine Park Authority	Water quality monitoring
James Cook University	
Earth Sciences Department	Projects not determined
Reef Research Centre	
Queensland Department of Primary Industries Warren Lee Long	Distribution and condition of sea grass communities
Southern Cross University, Centre for Coastal Management	
Peter Saenger, Bradley Eyre	Estuary classification; hydrology, sediments and nutrients
Leon Zann	Effects on the marine environment due to land use
Peter Harrison	ENCORE projects (nutrient fertilization of corals)

2.8. The effect of artificial watering points

2.8.1 Effect on groundwater resources

The extent to which extraction of groundwater by the pastoral industry is having an effect on groundwater resources was not a major component of this review and hence was not investigated to any great extent. It is worth noting, however, that the heavy withdrawal of water from the Great Artesian Basin aquifers by the large number of freely or mainly free flowing artesion bores has caused a marked lowering of regional pressure levels. Falls of several tens of metres have been reported in heavily developed areas with some bores showing falls of more than 100 m (Reville and Habermehl 1996). In 1989, a program of bore rehabilitation that involves piping and control of water flow was begun, to help conserve the groundwaters of the Great Artesian Basin.

As well as the need to conserve groundwater to maintain supplies for the pastoral and mining industries, and the rural communities dependent on them, groundwater is also critical for some vegetation communities. Hatton and Evans (1997) have recently reviewed what is known of the dependence of Australian ecosystems on groundwater. It is clear from this review that numerous vegetation communities in northern Australia are dependent, at least to some degree, on groundwater. These communities are not restricted to swamps and wetlands. The authors note, for example, that there is growing evidence that the upland tropical savanna woodlands (as well as the paperbark swamps and patches of monsoon rainforest) are dependent on groundwater in the dry season.

2.8.2. Effect on land and the regional biota

Cattle grazing is concentrated around watering points, with pasture utilization decreasing with increasing distance from permanent water. This concentration of grazing can result in pasture decline and loss of cover with consequent effects for soil erosion and soil condition. These effects of overgrazing are dealt with in other sections of this report (Chapters 3 and 4).

Artificial watering points can affect the regional biota by introducing permanent water to previously dry environments and through the heavier utilization by cattle (and kangaroos and feral animals) of land nearer the water supply. As indicated in Chapter 1, the effects of the grazing industry on the biological diversity of northern Australia was not encompassed by the scope of this review. Consequently, this issue is not dealt with here other than to note that in flora and fauna surveys along transects radiating out from watering points, major changes in the composition of the biota were found with increasing distance from the watering point (Landsberg *et al.* 1997). Some species increased, while others decreased, in abundance nearer to water while other species showed no change along the transect.

2.9. Summary

There is documented evidence that overgrazing pastures, clearing, pasture improvement (including ponded pastures) and fire management can all have deleterious effects on waterbodies and waterways, including wetlands and the marine environment. Effects include salinisation (clearing); damage to, and reduction in habitat value of, riparian areas and wetlands (grazing, pasture improvement, ponded pastures, fire management); and loss of flora and fauna. In these cases, the issues are the susceptibility of different land types and communities such as wetlands/riparian areas, to the processes of degradation, and the local grazing management regime.

The role of grazing and pasture improvement in the development of algal blooms is more equivocal. Several mechanisms seem to be involved in bloom development and greater understanding is needed of when and where particular factors give rise to excess algal growth before the role of grazing land management can be determined. However, input of phosphate and nitrogen to waterways can give rise to processes that are suspected of having a role in bloom development. Consequently, grazing management that leads to soil erosion or the direct input of nutrients to standing waterbodies, may be exacerbating bloom formation.

The effects the grazing industry may be having off-shore are also not so clear. There is evidence of deleterious effects of flooding and sediment deposition on seagrass beds but the extent to which this can be attributed to increased inputs of sediment and water due to grazing practices is unknown. In addition, our knowledge of the biotic communities of the north Australian coast is limited and this is another factor that restricts our knowledge of the effects of that grazing management may be having. There is no incontrovertible evidence for eutrophication in the Great Barrier Reef. There is anecdotal evidence for eutrophication in enclosed bays and nearshore fringing reefs. It is significant that in other bodies of water of similar size to the Great Barrier Reef, in which eutrophication has been documented, there was little evidence for eutrophication prior to major ecosystem collapse. Detecting anthropogenic eutrophication is also made difficult by the fact that the scale of natural variation is greater than that detectable by long-term trend analysis.

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3. POSSIBLE EFFECTS OF GRAZING AND LAND MANAGEMENT PRACTICES ON WATER, SEDIMENT AND NUTRIENT FLUXES

This chapter summarizes work on, and current understanding of, the effects that grazing and grazing management practices can have on water, sediment and nutrient fluxes from areas ranging from small plot through to large catchment. In extensive grazing systems, the principal management tool is stocking rate (head/ha). Levels of pasture utilization, however, are influenced by the length of time particular paddocks are stocked. Watering points and fencing are the main means by which the distribution of stock can be controlled, though fencing generally is limited in the rangelands. Other management practices of importance in the rangelands are burning of pastures, and in regions with relatively fertile soils, tree clearing and pasture improvement with sown grasses and legumes (see Chapter 2 for estimate of area suitable for pasture improvement).

3.1. Effects of grazing and grazing management on fluxes at patch to small catchment scales

3.1.1. Infiltration studies at patch scale

There have been investigations of the differences in the hydraulic conductivity/infiltration rates of surface soils in both grazed and ungrazed pastures at several localities in Queensland and the Northern Territory. These have typically measured differences in soil hydraulic conductivity between vegetated and non-vegetated patches (both natural and arising from heavy grazing) within particular plant communities. All studies, regardless of soil type and climate, have found rates of water movement into the soil profile to be higher under grass patches than in bare open areas, with rates in bare areas influenced by the period of time for which the soil had been exposed. Reduced infiltration rates in bare areas are generally attributed to surface seals as a result of raindrop impact. Loss of soil organic matter once plants are removed is thought to promote sealing in some instances, for example in the red-earth soils studied by Mott *et al.* (1979). Also plant tussocks are associated with the presence of macropores which increase soil hydraulic conductivity. Possible origins for the macropores are that they are old root channels or that they are due to soil organism activity.

Differences in infiltration rates between sites with different plant species growing on the same soil type have been found in some experiments. For example, infiltration rates under *Heteropogon contortus* patches have been found to be higher than under *Chrysopogon fallax*. Although macroporosity was higher in soils under *H. contortus*, the reason for this difference was unclear. In some preliminary infiltration studies carried out with a disk permeameter at the Galloway Plains Grazing Trial (Calliope River catchment, Qld), pastures with Seca Stylo were found to have infiltration rates lower than those with either *H. contortus* or *C. fallax*. There have been limited infiltration experiments associated with burning. The effect on infiltration rate seems to be associated with the resultant soil exposure.

3.1.2. Plot scale hydrological studies

Large plot scale (30 m^2 to 0.25 ha) hydrological studies have been undertaken in the seasonally dry and semi-arid regions of Queensland and the Northern Territory. These have mostly been associated with grazing trials and have investigated the effects of stocking rate on plant cover, runoff and sediment movement. Only two of the studies from which information was obtained for this review, have measured nutrient loss. One study, that by Bonell and Williams (1986, 1987) involved investigation of the natural hydrology of an undissected plain near Torrens Creek in Queensland. This investigation found substantial variation in runoff and infiltration within the slope although only 2% of total rainfall was exported from the slope. A severe fire increased the amount of sediment movement within the 100 m slope but there was no increase in the net loss of sediment during the time frame of the experiment.

The results from measurements of runoff and soil loss under different grazing regimes were highly variable and depended on cover and rainfall intensities and amounts, although losses under heavier stocking rates were nearly always higher than under lighter grazing or in exclosures. For example, low runoff and sediment losses from plots have been shown to be correlated with high plant cover. As cover decreases, the amount of water and sediment loss increases. In some studies (eg, McIvor *et al.* 1995), around 40% cover has been found to be a threshold value above which runoff and sediment loss are relatively low but below which there is an exponential increase in water and sediment loss.

While small plot studies have shown that increases in runoff will result in increased export of sediment and nutrient, significant runoff events from small plots do not always translate into significant runoff from landscape plots (for example, Sallaway and Waters 1994). Runoff from plots is controlled by the spatial variability in surface hydraulic properties, particularly between bare and vegetated patches. Not only have vegetated patches been found to have higher hydraulic conductivities, but they increase the microtopography of the soil surface, creating surface depressions which increase surface water storage and reduce runoff. They also increase surface roughness which reduces the velocity, and hence the erosion potential, of overland flow. In ungrazed and lightly grazed pastures, there is usually a high degree of heterogeneity in soil surface properties associated with the distribution of numerous tussocks. In the tropical and subtropical seasonally dry woodlands with grass understoreys, for example, this spatial heterogeneity occurs in areas of less than one metre while in arid and semi-arid landscapes, the distance between patches is larger (Williams *et al.* 1993). With an increase in grazing pressure, plant cover is reduced, the bare areas increase and there is consequently a reduction in spatial heterogeneity. The increase in bare patches reduces the amount of infiltration and increases runoff. Once critical thresholds in plant cover are reached, more water is generated than is able to infiltrate within the remaining patches and there is an increase in net water loss. Associated with the increased runoff is an increase in erosion and sediment loss.

In the arid zone, soil loss studies have focussed on the development of 'erosion cells' rather than on plot measurements. 'An erosion cell' (Pickup 1985) encompasses the sediment production zone, the sediment transfer zone and the sediment deposition zone or sink. The deposition zones are generally associated with higher plant productivity. Under natural conditions, terrain in the arid zone is characterized by a mosaic of erosion cells, often superimposed on each other and with areas or relative stability between them. With the imposition of grazing, soil from the small erosion cells tends to be mobilized first, creating larger runoff or production zones. Increased runoff and sediment transport occurs and the increased sediment is only able to be trapped in the larger deposition zones. Consequently as a result of grazing, 'erosion cells' tend to decrease in frequency and increase in size. Grazing similarly induces a loss of spatial heterogeneity in these environments as was described above for the seasonally dry woodlands.

From the point of view of water quality, the important consideration is the net water and sediment loss from the local landscape (ie, the amount of water and sediment actually reaching the drainage channel). David Tongway (pers. comm.) has commented that although we can observe increased losses from patches and plots, we mostly do not know what is being lost from the local landscape. Losses from the local landscape will depend on the heterogeneity in soil properties and vegetation type as well as on the local topography.

3.1.3. Small catchment studies

Losses of sediment have been measured for small catchments in the Burdekin, Dawson, Burnett and Nogoa River catchments in Queensland. The investigations in the Dawson and Burnett catchments involved paired catchment approaches to determining the change in runoff and sediment loss following clearing and sowing to pasture. Clearing of Brigalow (*Acacia harpophylla*) and planting to buffel grass (Dawson catchment) resulted in an increase in mean runoff from 23 mm to 47.4 mm while average suspended sediment loss per event was 19 kg/ha for brigalow and 32 kg/ha for pasture (Lawrence and Thorburn 1989). In the Narayan small catchment study, it was concluded that provided a good grass cover were maintained, clearing woodland with *Eucalyptus melanophloia* and black spear grass (*Heteropogon contortus*) and sowing to improved pasture would not greatly affect runoff.

The Springvale catchment study (Nogoa River catchment) compared runoff from the catchment under grazing and, subsequently, with grazing excluded. Runoff from the catchment after the pasture had grown following exclosure from grazing was about 15% of rainfall while during grazing, runoff averaged 28% of rainfall over a period of four years.

3.1.4. Water balance studies and recharge investigations

The low topographic relief in many regions of northern Australia suggest relative high infiltration rates. Despite what would seem to be a geomorphic predisposition to high rates of infiltration in many areas of northern Australia, there have been few studies quantifying components of the water balance, including deep drainage, and the effects of grazing land management on recharge.

Williams and Coventry (1979 and 1980) investigated the soil water regime of red, yellow and grey earth profiles at Torrens Creek in the Burdekin catchment and found soils saturated during the wet season in some years. As a result, they concluded that there was potential for episodic groundwater recharge below these soils, despite the semi-arid environment. Barnes *et al.* (1992), in a study of nitrate contamination of groundwater near Ayers Rock, concluded that significant episodic recharge was occurring. A subsequent study using pre-existing bore data suggested a long-term annual recharge rate of about 20 mm/yr (Barnes *et al.* 1994). This latter study also noted that although localized recharge occurs in the arid zone as a result of infiltration through the beds of ephemeral streams, distributed recharge was likely to be the major source of groundwater renewal in the area they studied.

Circumstantial evidence for an increase in recharge following clearing comes from the development of dryland salinity in the south-east of Queensland, particularly in basaltic areas (Gordon 1991). The only field studies that have investigated the effect of clearing on soil water regime are those at 'Redlands' (45 kms west of Charters Towers in the Burdekin catchment), and the paired catchment experiments at the Brigalow (Dawson) and Narayan (Burnett catchment) Research Stations. The 'Redlands' field experimental work involved measuring the comparative water balance of the natural eucalypt woodland, the native grasses (*Heteropogon contortus* and *Chrysopogon fallax*), and *Stylosanthes* pastures with adequate and suboptimal levels of phosphate application. Clearing and the introduction of pastures had a clear effect on the water balance, with plant water use reduced in treatments with native grasses and *Stylosanthes* pastures only (Williams *et al.* 1997). Numerous studies in southern Australia have shwon that reduced plant water use results in higher soil water contents and an increase in the likelihood of recharge.

At the Brigalow experimental site, clearing brigalow and its replacement with buffel grass pasture resulted in a 23 mm/yr increase in recharge (30 mm/yr under pasture compared with 7 mm/yr under natural brigalow) in a very high rainfall year prior to complete pasture establishment (Lawrence and Thorburn, 1989). In lower rainfall years there was no recharge under either the brigalow or buffel grass pasture. Similarly, Prebble and Stirk (1988) found little change in the soil water regime and deep drainage at the Narayan catchments between cleared sites sown with Sirato and green panic and the *Eucalyptus melanophloia* open woodland with *Heteropogon contortus*. The lack of change in the water regime was attributed to most trees having similar rooting depths to the pasture plants.

In addition to field studies, simulations of the soil water regime using models have also been carried out to help determine the potential for increased recharge following clearing and pasture establishment. Williams *et al.* (1997) used the SWIM and PERFECT models to extend the soil water balance measurements made at the 'Redlands' site. These simulations suggested that:

- over the period January to June 1980, deep drainage increased by a factor of ten in the native grassland without trees compared with the woodland (86.1 mm and 8.9 mm respectively);
- a red earth, sandy red earth and yellow podzolic soil each exhibited increased drainage under native grasses compared with under trees and native grasses; and
- over a 100 year rainfall record period (1889-1988), deep drainage was episodic, with the occurrence of deep drainage increasing from 17% to 66% of years in the red earth soil once trees were removed from the landscape. For the neutral red duplex soil, the suggested increase was from 4% of years to 42%.

3.1.5. Current and proposed research

Listed below are current research projects and projects which have been put forward for external funding but not yet approved.

Title	Contact	Issue	Location
Water balances in the natural system			
Water use by savannas	Derek Eamus, NT University	Estimation of sustainable groundwater pumping rates	Savanna woodlands near Darwin, NT
Hydrogeology of the Great Artesian Basin	Jim Kellet, Australian Geological Survey Organisation	Quantification of recharge from all sources, particularly river leakage compared with diffuse rainfall	Great Artesian Basin
Suppression of meso-scale heterogeneity by the tree layer in a tropical woodland	Joel Brown, CSIRO Tropical Agriculture	The effects of individual trees and tree clearing on the distribution of soil resources including water	Near Charters Towers, Qld
Soil water and nutrient change following clearing and pasture improvement			
Sustainability of Stylosanthes *pasture system in northern Australia: managing soil acidity*	Andrew Noble, CSIRO Land and Water	Assessment of long-term soil fertility and soil water trends under *Stylosanthes* and native pasture systems	Various sites in northern Qld and the NT
Surface water, sediment and nutrient fluxes			
Brigalow Experimental catchment studies	Bruce Cowie, Qld Department of Natural Resources	Nutrient and sediment losses in runoff	Brigalow Research Station, Qld
Coping with rainfall variability: grazing management strategies for seasonally variable tropical savannas	Peter O'Reagain, Qld Department of Primary Industries	Water, nutrient and sediment loss from 50 ha subcatchments	Near Charters Towers, Burdekin Catchment, Qld
How long will soils last with current grazing practices?	Mark Silburn, Queensland Department of Natural Resources	Effect of sediment and nutrient losses on pasture productivity	Balonne and Nogoa catchments, Qld
Land management to reduce nutrient movement from catchments	Geoff Titmarsh, Queensland Department of Natural Resources	Nutrient composition and contribution from different soil types and land uses	Qld catchments within the Murray-Darling Basin
Water quality in the Fitzroy catchment	Don Yule, Queensland Department of Natural Resources	Effects of agricultural production on water quality	Fitzroy catchment, Qld

3.2. Effects of grazing and grazing management on fluxes from large catchments and river basins

3.2.1. Studies investigating the effects of grazing on catchment sediment and nutrient fluxes

Although "overgrazing" has been found to reduce infiltration and increase runoff and erosion within patches and small plots, this increase does not immediately translate into increased sediment and nutrient fluxes at a river mouth or even the outlet of a large subcatchment. Determining the change in fluxes that can be attributed to grazing is much more problematic at large catchment to river basin scales (thousands of square kilometres). While in the more humid climates at least, runoff and dissolved nutrients will be carried relatively rapidly from source areas to the coast, the same is not true for sediments and their sorbed nutrients. Sediment and associated sorbed nutrients eroded from a slope can be deposited downslope or downstream either on floodplains or within the channel network. The distance sediment is transported before deposition is related to its size — very fine particles tend to remain in suspension, and hence these particles and their associated nutrients will be transported further than larger, heavier particles. This further complicates the pattern of sediment generation and transport.

While changes in runoff and erosion (sediment generation) as a result of grazing have been investigated at plot and small catchment scale, there have been virtually no attempts to determine how far and over what periods of time, the eroded material is transported through a catchment, and how subsequent transport and deposition processes are themselves influenced by grazing. Consequently there is little understanding of how grazing has affected the flux of sediment and nutrients leaving large catchments.

Despite the limitations of the method, several studies have adopted a 'scaling up' approach using plot and small catchment measurements to estimate the effects of grazing on whole catchment sediment and nutrient fluxes. For example, Moss *et al.* (1993) developed two simple statistical models to estimate sediment and nutrient exports from Queensland coastal catchments. The first was based on flow-weighted sediment concentrations and annual average stream discharge. The second took into account land use, catchment erosion rates and a sediment delivery ratio. Moss *et al.* estimated current sediment loads from all Queensland coastal catchments as being 3-4 times greater than pre-European loads. They also concluded that about 84% of sediment from Queensland coastal catchments is from grazing land. Given the large area of the coastal catchments occupied by grazing, however, this figure is hardly surprising. It appears to be indicative more of the proportion of land used for grazing than of the amount of erosion and sediment transport from grazing land.

Neil and Yu (1996) used sediment concentration and daily streamflow data for the Barron, Tully, Herbert and Burdekin Rivers, Babinda Creek and the headwaters of the Flinders River, to estimate sediment yields of all streams discharging into the Great Barrier Reef lagoon. They estimated the proportion of current nutrient export to the Great Barrier Reef lagoon attributable to natural processes, grazing and cropping as 26%, 66% and 8% respectively. Again, these estimates are probably a reflection of the proportion of the total area occupied by these land uses. Although the estimates of sediment yields in this study do not represent a 'scaling up' from plot and small catchment data as much as the estimates of Moss *et al.* (1993), there are extrapolations between catchments, not all of which have the same climatic regimes and land types.

An alternative to summing runoff, sediment and nutrient fluxes measured on plots and for small catchments across the whole catchment, is to monitor fluxes at the catchment mouth and to correlate change in flux with a major change in catchment land use, such as the introduction of grazing. An immediate problem here, however, is the subsequent deposition of eroded sediment that may occur, resulting in the episodic movement of sediment through a catchment and unkown time-lags between the introduction of changed land use or management and change in sediment flux at the catchment mouth. Another problem is that monitoring records post-date changes of interest or a sufficiently long monitoring record is not available to distinguish between changes due to variation in climate and those attributable to grazing. Consequently, no studies using river monitoring data to investigate the effects of the introduction of grazing on fluxes of sediment and nutrient were found during this review. Andrew Ash, however, has a proposal to correlate plant cover with rainfall and Burdekin River flow regime (A. Ash, pers. comm.). Since heavy grazing is known to influence cover, a correlation between river flows and cover would strongly suggest a grazing influence on flows.

Other methods for investigating changes in catchment sediment and nutrient flux over time include examination of near-shore sediment cores. Changes in the rate of sediment deposition can be used to indicate changes in sediment flux due to land management changes. There are, however, several criteria which must be satisfied for a locality to be suitable for obtaining cores. For example, the locality should not be subject to physical disturbance, there need to be sufficient rates of sediment deposition for deposition to occur over relatively small time intervals and the period of deposition must be of sufficient length to cover the time span of interest. It is often difficult for all these criteria to be met. Sediment core work is currently being undertaken in the Herbert River catchment and a project to use sediment cores to reconstruct changes in carbon and nitrogen inputs is planned for the Fitzroy River catchment in Queensland.

In a similar but slightly different approach to assessing changes in terrestrial inputs to the Great Barrier Reef lagoon, scientists at the Australian Institute of Marine Science are using cores taken from coral colonies. Coral colonies have life spans greater than 200 years and, since they contain a record of the natural variability in coral growth prior to European settlement, cores from them can be used to assess growth changes due to anthropogenic activity.

Despite these various investigations of terrestrial inputs from coastal catchments, the issue that is still not clear, is the increment in the flux of sediments and nutrients from the land over that which occurred in the ungrazed state. Given the large proportion of many catchments that is used for grazing, it is to be expected that land used for grazing will contribute a high proportion of the sediment and nutrient transported from a catchment. It is the increment in sediment and nutrient transport within and from catchments as a result of grazing that is important, not the total amount of sediment contributed by grazing lands. It is not realistic to try to reduce the flux of sediment and nutrient to below that which occurred under natural conditions.

3.2.2. The capacity of landscapes to generate and transport sediment

As indicated in Section 3.2.1., there have been few investigations of how large catchments function in terms of sediment and nutrient generation, transport, and deposition or of the effects of grazing on these processes. Estimates of catchment sediment and nutrient fluxes have either been based on plot studies, which effectively assume that land use is the primary factor controlling runoff and soil loss, or they have investigated exports from the whole catchment and correlated these with known changes in grazing management to obtain an indication of the effects that grazing may be having. An aspect of catchment function which generally has not been considered, let alone investigated, is the variation in the inherent capacity of different landscapes within a catchment to generate and transport sediment.

Work by Aldrick in the Ord and Roper River catchments and the Southern Gulf Region of the Northern Territory (Aldrick *et al.* 1978, Aldrick and Wilson 1990, 1992), suggests that not all landscapes are equally likely to contribute sediment at a catchment mouth. In the land resource assessments of these areas, Aldrick has identified geomorphic provinces, where a geomorphic province is "*an area of land having attributes of landform and/or soils and/or vegetation that differ consistently from those of other terrain, because of the direct influence of a geomorphological landscape-forming process or processes operating there but not operating elsewhere at the same rate*" (Aldrick 1985). Geomorphic processes that have operated in a landscape over long periods of time, and that are still operating there today, exert a dominant natural influence on sediment supply and transport. Some of these geomorphic provinces are relatively stable and unlikely to deteriorate substantially, but others are inherently unstable. Disturbance of vegetative cover and topsoil in the more vulnerable geomorphic provinces can increase sediment and nutrient output substantially; much more so than in the more stable geomorphic provinces. As a result each province has an inherent capacity to generate and transport sediment towards the coast. Whether this inherent tendency is accelerated or not depends primarily on whether the controls imparted by the vegetation and soil are impaired, for example by grazing and land management practices.

As well as this landscape scale variation in the capacity of land to contribute sediment to a river mouth, there is also variation at more local levels. Recently several authors have pointed out (eg. Finlayson and

Silburn 1996, Wasson 1996) that the relationship between slopes and channels is important in determining the time-frame over which sediment eroded from a slope is likely to be transported from the subcatchment. Where slopes and channels are directly connected, sediment from the slope will more quickly reach a channel compared with areas where the slope is separated from the channel by flat or very gently sloping land, such as a floodplain. Sediment reaching the flat terrain is likely to be stored there for considerable periods before being eroded by floodplain scour or eventually channel erosion. Riparian vegetation has also been considered to be important in filtering, and storing at least temporarily, sediment and absorbed nutrients from water running off the land into the waterway. Despite recognition of this possible role of vegetation, there are very few data quantifying the effect that vegetation can have, how this might vary for different land types and stream orders, and the effect that grazing riparian vegetation has on this filtering function. Work on the filtering role of riparian vegetation is being undertaken in the National Rehabilitation and Management of Riparian Lands Program being funded by the Land and Water Resources Research and Development Corporation. There are few investigations, however, directly associated with grazing lands although generic information will be provided which should be tested in the northern Australian rangeland environment.

Sediment tracing studies can be used to determine the source of sediment, both in terms of geographical location and whether the sediment is derived from sheet and rill erosion, or from gullies and channels. The only sediment tracing work identified during this review was that by Wasson *et al.* (1994) for the Ord River catchment. An important outcome of this work was that only about 10% of sediment in Lake Argyle was considered to be derived from sheet erosion, the remainder coming from gullies and channels.

Given the likely importance of gullies as a source of sediment, the possible effects of grazing on gully development and stability are just as important as the possible effects of grazing on sheet and rill erosion. There have been, however, fewer studies relating to gullies. Finlayson and Brizga (1993) have investigated the incision of an anastomosing stream in the Nogoa River catchment in central Queensland. Incision occurred subsequent to the introduction of grazing and Finlayson and Brizga suggest that loss of vegetation cover and disturbance of the soil surface by cattle may have initiated channel incision.

3.2.3. Current and proposed river basin water quality and catchment management projects

Title	Contact	Issue
Water quality research for the Fitzroy River, Qld		
Water quality in the Fitzroy catchment	Don Yule, Department of Natural Resources, Qld	Effects of agricultural production on water quality
Coastal zone research in the Herbert River catchment		
Climate record	Janice Lough, Australian Institute of Marine Science	Climate variability over the past several centuries using proxy records from massive corals
Isotopic studies of organic carbon	Michael Bird, Australian National University	Processes controlling the carbon-isotope composition of carbon in the terrestrial carbon pool
Effects of rural land use on water quality	Rob Bramley and Christian Roth, CSIRO Land & Water	Quantification of the effects of rural land uses in water quality in the lower Herbert River
Nutrient and sediment delivery from the Herbert River	Chris Barnes, CSIRO Land & Water	Quantification of major nutrient fluxes from the Herbert River to the Great Barrier Reef lagoon.

Sediment history of the Herbert River floodplain	Bob Wasson, Australian National University	Quantity of sediment and P deposited on the Herbert River floodplain and any variation in post-European deposition
Marine biogeochemistry and sedimentation history	Gregg Brunskill, Australian Institute of Marine Science	History of sediment accumulation on the continental shelf near the Herbert River mouth
Biological resources of beds of the tropical continental shelf	Roland Pritcher, CSIRO Division of Marine Research	Factors determining the distribution the distribution, abundance, population dynamics and productivity of tropical continental shelf seabed resources
Decision support development	Andrew Johnson and Daniel Walker, CSIRO Tropical Agriculture	Effective tools for assisting the management of natural resources in northern Australia
Research in the North Johnstone River catchment, Qld		
National Rehabilitation and Management of Riparian Lands Program —Aspects of physical and chemical processes	Ian Prosser, CSIRO Land & Water	Sediment budgets, sediment and nutrient filtering by riparian vegetation and effect of cattle access to streams on sediment and nutrient fluxes to waterways
National Rehabilitation and Management of Riparian Lands Program —Ecological issues	Stuart Bunn, Centre for In-Stream and Catchment Research, Griffith University	Para Grass, Bamboo Creek, Innisfail
Nutrient balances and transport from agricultural lands	Brian Prove, Qld Department of Natural Resources	Nutrient and sediment removal from agricultural land and the mechanisms and pathways for their removal
Water quality monitoring and modelling	Heather Hunter, Qld Department of Natural Resources	Quantification of sediment and nutrient loads entering the GBR from the Johnstone River

3.3. Summary

Cattle grazing can have a marked effect on sediment and nutrient loss when losses are measured at patch and small plot scale. Not all grazing, however, results in increased loss of sediment and nutrient. Erosion studies have shown runoff and sediment loss to be related to plant and ground cover. At relatively high covers, net water and sediment fluxes from erosion plots mostly have been small, increasing with a decrease in cover. In several studies in the wet/dry tropics and subtropics, ground cover of around 40% has been found to be the value below which there is a marked increase in runoff and erosion. Consequently, while stock numbers and grazing pressure are such that relatively high plant and ground cover levels are maintained, there is little water and sediment loss. Once grazing pressure increases, however, plant and ground cover are reduced. Loss of cover increases the exposure of soil to raindrop impact and surface sealing is likely. Loss of plant cover is also associated with a loss of soil macropores although the mechanisms involved are not clear. It may be related to loss of soil organism activity and/or loss of plant roots. Sealing and loss of macroporosity reduce infiltration, increasing runoff. Loss of cover also reduces the degree to which surface flow is impeded and exposes soil to removal by flowing water. The increase in runoff and its velocity, along with the exposure of soil to erosion, result in an increase in sediment loss.

In addition to exposing soil to raindrop impact and overland flow, loss of cover exposes the soil to trafficking and compaction by cattle. Compaction not only reduces infiltration, as with sealing, but reduces the surface microtopography. Small depressions in the soil surface store rainfall, reducing runoff and increasing infiltration. Their loss further increases runoff.

The head of cattle per hectare which will cause critical ground cover levels to be reached, is highly variable both in time and space. The amount of cover at any time depends on the relationship between plant growth and plant consumption. Different land types have different capacities for plant production, related to their inherent nutrient fertility as well as to their soil water holding capacity. They also have different inherent susceptibilities to soil loss as a result of different slopes, inherent tendency to seal, particle size characteristics of surface soil, and so on. There are also marked differences in plant productivity over time in any given land type, arising from differences in seasonal rainfalls. As a result of differences in land type and season, cattle numbers need to be adjusted both spatially and temporally. From the point of view of tactical management, the concept of 'average' carrying capacity has little meaning. A large part of the degradation that is currently observable in the rangelands (see Tothill and Gillies 1992) is the result of the mismatch between animal numbers and plant production (for example, see Figure 1.1 in Chapter 1). Avoiding pasture degradation and the resultant loss of soil and nutrients will require improved management of stock numbers. In the past, large properties and holdings throughout the rangelands enabled pastoralists to move stock and adjust stock numbers according to seasonal conditions on any property. Reduced property sizes limit this capacity and economically viable alternatives for adjusting stock numbers are required. In those areas of the rangelands where seasonal conditions are usually related to the Southern Oscillation Index, improvements in prediction of the index should help pastoralists with strategic stock management.

Burning pastures is another mechanism by which plant and ground cover can be reduced. Consequently, this management strategy has also been found to increase runoff and sediment loss in comparison with unburnt pasture, with the increase depending on the length of time for which the soil has been exposed following burning. Differences would also be expected between different land types.

Modelling work indicates that an increase in episodic recharge is likely in many parts of the semi-arid to wet/dry tropics as a result of clearing, although very few experimental hydrological investigations have been carried out. This is changing, however, with the work being done in the NT on water balances in the natural system and in the Balfes Creek area in the Burdekin Catchment. Also, sustainable water use in the Great Artesian Basin is increasingly becoming an issue. The Australian Geological Survey Organisation has developed a groundwater model for the Basin and now require quantified data for recharge flux from all sources, both river leakage and diffuse rainfall recharge, to be able to confidently predict resource performance. It is therefore likely that some recharge studies will be undertaken in landscapes overlying the intake beds of the Great Artesian Basin. Likely change in components of the water balance following clearing and pasture improvement in different land types, remains one of the major unknowns across northern Australia.

While increases in the flux of water, sediment and nutrient have been measured at local scales, at particular stocking rates and as a result of burning or pasture improvement and clearing, the effect of these increases on the flux of sediment and nutrient leaving a large catchment is virtually unknown. Consequently, the downstream effects of stock numbers exceeding the productive capacity of pastures is also unknown. Various estimates have been made of the effect of increases in local fluxes on the discharge of sediment and nutrient from whole catchments but these estimates take no account of eroded material that is subsequently deposited before reaching a catchment mouth. It is expected that any increase in very fine sediment transported to a channel as a result of grazing, will result in an increase in the export of very fine sediment, and attached nutrients, as such sediment is likely to remain suspended in the water column. The same is not true, however, for coarser particles. The estimates of changes in sediment and nutrients exported from a catchment often also assume that different land types will have similar soil losses provided land use is the same. Consequently, the estimates can best be considered a first approximation.

Alternative methods for assessing the effect of the introduction of grazing on catchment sediment and nutrient export include examination of near-shore sediment cores for changes in the rate of sediment deposition, and of corals for changes in growth rate. Work currently being undertaken by the Australian

Institute of Marine Science is assessing the use of coral cores for determining the past occurrence of episodic flooding.

Work is needed to delineate the different landscapes and to determine their inherent tendencies to contribute sediment at a river mouth. This involves both an understanding of the inherent tendency of a landscape to produce and transport sediment of different size classes as well as sediment tracing to help identify the different geographical locations and sources (slopes and plains, gullies, channels or floodplains) contributing sediment to the channel network. Only then can the effects of grazing in different landscapes within a catchment, on catchment sediment and nutrient fluxes, be determined.

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4. POSSIBLE EFFECTS OF GRAZING ON LAND RESOURCES AND THE GRAZING INDUSTRY

The main focus of this review has been the off-site effects that grazing and grazing management can have. While these are extremely important given the wide geographic spread of the northern Australian beef industry and hence its potential to affect a large number of riverine, wetland and marine environments, it is also worthwhile to briefly consider some of the on-site effects grazing and grazing management can have on the vegetation and soil, and the processes within them. Effects on the land are critical for the grazing industry itself as they will eventually influence animal production and hence profitability. Some of these effects are discussed in this chapter.

As was noted in Chapter 3, not all grazing or grazing management is associated with land degradation and off-site water quality effects. Most degradational problems only arise when pasture utilization levels and trafficking and trampling are such as to allow thresholds in biophysical properties of the land to be exceeded, such as percent cover, so that processes which reduce the productive capacity of the land, and which are regarded as deleterious, occur. It should be noted, that other grazing animals, such as kangaroos and feral animals, can all contribute to the pressure on the pasture resource, and that erosion and other degradational processes can be initiated by activities other than grazing. Tracks, for example, can be a major cause of erosion.

4.1. Loss of landscape function

The introduction of grazing, as with any land use, affects the natural environment and the processes within it, by altering characteristics of the vegetation and soils. The degree of change within the landscape depends both on the characteristics of the particular landscape and on the degree and type of utilization of the area by cattle. In landscapes with heavy use, loss of vegetation cover, change in species composition and change in condition of the soil, are readily apparent. While change in species composition has direct implications for biological diversity, the other important issue from the point of view of sustainability of the grazing resource, is the change in processes or land functioning. Such changes are not easily visible although there has been considerable work within the CSIRO Division of Wildlife and Ecology to link land function with indicators that can be readily observed in the field (eg, Tongway and Hindley 1995).

Loss of landscape function is associated primarily with loss of vegetation, though current work associated with the project *The determinants of land degradation in wet/dry tropical savannas*, suggest that other factors may also be necessary (Garry Cook, pers. comm). Loss of vegetation exposes the soil to raindrop impact and this, combined with the associated loss of organic matter (through greater oxidation and reduced litter return), can result in surface sealing and reduction in water infiltration. Soil organisms can also exert a significant influence on infiltration. For example, Holt *et al.* (1996) showed that a reduction in the biomass and diversity of termites caused by heavy grazing pressure over a period of six years, caused a 70% decline in soil hydraulic conductivities. An increase in bare, sealed areas increases runoff and also represents a loss of "patchiness" in the landscape. Grass patches have been found to trap litter, sediments and seeds and as patchiness is reduced, these materials are lost from the local landscape. The role of vegetation patches in landscape function has been extensively described in the recent book *Landscape Ecology, Function and Management: Principles from Australia's Rangelands* (Ludwig *et al.* 1997).

4.2. Implications of increased water, sediment and nutrient loss for land and animal productivity

4.2.1. Water

The data of Silburn *et al.* (1992) for a site in central Queensland demonstrate quite clearly the significance of water loss from systems with very low plant cover. They measured runoff that accounted for 50-60% of the annual rainfall on plots with less than 10% plant cover. As the authors point out, at this site, a pasture with low cover effectively experiences a drought (320-420 mm water available for growth) in a year of average rainfall (790 mm). Various studies (eg Friedel 1981a, McIvor *et al.* 1995) have quantified the reduction in biomass production that can occur on land in poor condition. Some of this reduction would be due to the reduced water availability from the decrease in infiltration and increased runoff.

4.2.2. Nutrients

Plot and small catchment studies have generally not measured nutrient export so that there are very few data on nutrient loss rates associated with runoff and erosion, and on the significance of these losses either in terms of the proportion of nutrient removed from different land types or the affect of this removal on future productive capacity. Silburn (1996) in a project proposal for NHT funding (*How long will soils last with current grazing practices*?) quotes loss rates of 10% of total N and P over two recent very dry years, for a site in SE Queensland. This was the only data found that correlated measured nutrient loss rates from a soil, with the soil nutrient reserves. Further data on the effect of grazing on soil nutrient losses and soil nutrient reserves will be available from model simulations in this project for soils (which ones were not specified) of *Aristida—Bothriochloa* woodlands in the Balonne/Maranoa and Nogoa/Fitzroy catchments.

Several studies give data on the distribution of nutrients within the soil which allow some assessments to be made of the effects of erosion. For example, Pressland (1985) provides data on organic carbon, total N and P, and available P at various depths in the top metre of the profile for mulga lands, although the particular soil type is not given. He points out that loss of the top 5 cm of soil results in loss of 13% of the available P, 9% of total N and 11% of organic carbon. Further more, when the top 5 cm of soil is removed, the next 5 cm contains only 50% of the P that was available in the original surface soil. Production of wire, mitchell and buffel grasses grown in pots with soils from 5 cm depth was found to be about half that of the same grasses grown in soil from the top 5 cm. Similarly, Tongway and Ludwig (1994) provide data on nutrient reserves for a neutral red earth soil with a wooded grassland near Katherine in the Northern Territory. In grassy areas, organic carbon and available phosphorus in the top 1 cm of soil were more than double the amounts from 1-3 cm. Low fertility soils commonly seem to have a relatively high proportion of total nutrients in the topsoil (Charley and Cowling 1968, cited in Friedel 1981).

Losses of topsoil nutrients would seem to be critical for the long-term sustainability of pastures but there seems to be little knowledge about long term effects. The GRASP (GRASs Production) model developed for northern Australian pasture systems is being used in the project "*How long will soils last with current grazing practices*?" to estimate the effects over time of continued nutrient loss on plant biomass production. As well as total production, another critical issues is the affect of loss of nutrients on vegetation state. That is, do we know if once a certain nutrient threshold has been crossed, whether it is possible to return to an alternate vegetation state?

Friedel *et al.* (1980) did some work that investigated the relationships between nutrient deficiencies and range condition in Central Australia. They concluded that P is the only nutrient which is potentially more deficient on degraded rangeland soils compared with healthy rangeland soils but that evidence for a relationship between range condition and phosphorus deficiency was inconclusive. They did find, however, under glasshouse conditions, that decreaser species (species which decrease in abundance with increased grazing or other use which disturbs the natural ecosystem) growing on mitchell grassland and open woodland soils from poor condition areas responded better to phosphorus addition than they did if growing on soils from areas in good range condition. Increaser species growing on soils from degraded areas of mitchell grassland also responded better to phosphorus addition than those growing on soils from good areas while increaser species growing in woodland soils were insensitive to phosphorus addition.

A further study (Friedel 1981a,b) that sampled nutrients in soils from *Astrebla* grasslands, open woodlands and *Acacia* shrublands in excellent, good and poor condition found some evidence for correlation between extractable phosphorus and range condition in *Astrebla* grasslands and open woodlands. When soil from sites in different condition over a larger geographic area were sampled, little correlation with extractable phosphorus (or nitrogen or sulphur) was found.

The studies of Friedel suggest that in the vegetation communities studied, nutrient level on its own is not determining plant composition in the degraded state. The factors resulting in changed species composition are not clear and it would be useful to know the mechanisms involved, for example, whether factors such as reduced activity of soil biota and reduced infiltration, increased soil temperatures, and/or reduced seed production are involved. It may also be that a lower nutrient status can cause other factors to become limiting for a particular species when they would not be limiting at higher nutrient levels. The current project, *Determinants of land degradation in tropical savannas* may provide some further information.

4.2.3. Effects on animal production

Ash and McIvor (1995) investigated the effects of land condition at sites on different soils at Katherine and Charters Towers, on herbage quality. Over all sites, they found a significant increase in digestibility and nitrogen concentration and a significant decrease in phosphorus concentration, as condition declined. This suggested that, at least in the short-term diet quality may be higher on land in poor condition. A study of the effect of land condition on animal production showed variable changes in animal liveweight (g/hd/day) depending on stocking rate. At both Charters Towers and Katherine, low stocking rates (1 or <1 animal per ha, and 2 or <2 animals per ha, respectively) on land with State II vegetation (moderate disturbance; perennial and annuals) resulted in greater liveweight gains than land with vegetation in State I (relatively undisturbed perennials). At higher stocking rates, the reverse was true due to the effect of the decreased production of State II vegetation.

That animal production is not simply related to land condition suggests that using vegetation and soil indicators of land condition on their own will not necessarily lead to management changes. It will be necessary to demonstrate to graziers the economic and ecological benefits of returning to State 1 vegetation. These benefits may be related to the greater productivity of State 1 vegetation, lower risk of fodder shortage (particularly during dry periods), and long-term maintenance of soil fertility.

4.3. The dynamics of land and grazing systems, and some knowledge gaps

Hutchinson (1997) identified the key linkages which we need to understand in our land—grazing systems if we are to manage them so that the productive potential of the land resource is maintained, where the land resource includes pasture, soil and water (figure 1). It is useful to consider the research in northern Australian grazing systems in terms of these linkages. It seems that there is understanding about the effects of grazing on pasture species for at least some vegetation communities, as shown by the development and use of the various state and transition models (eg. *Tropical Grasslands* **28**, 195-279). There also seems to have been considerable work on pasture species and animal production, and the effect on these of soil fertility though these aspects have not been covered by this review. This review has identified work on the effects of overgrazing on infiltration and runoff, and in reducing the heterogeneity of the soil surface and vegetation cover. For example, a reasonably large body of information seems to be being built up on the functioning of rangeland landscapes in terms of the distribution of vegetation and its effect on water and material (sediment, nutrient, litter, seed) transfer and accumulation processes, and of the effect of grazing on these processes (see, for example Ludwig *et al.* 1997 and numerous references within this).

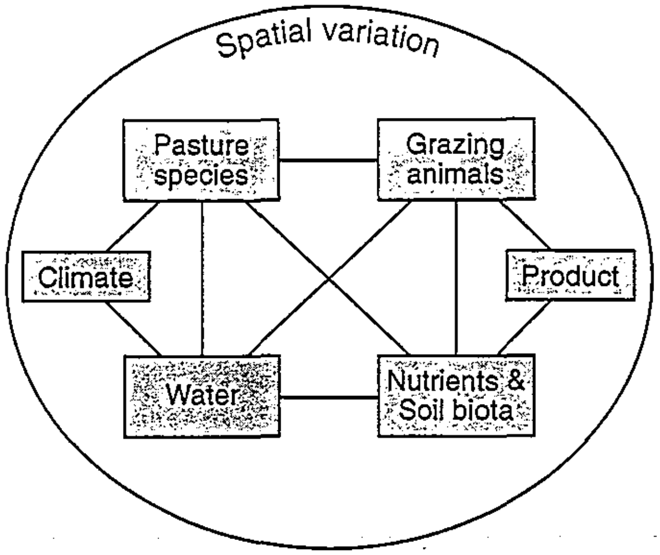


Figure 1. Key linkages between grazing system components (From: Hutchinson 1997)

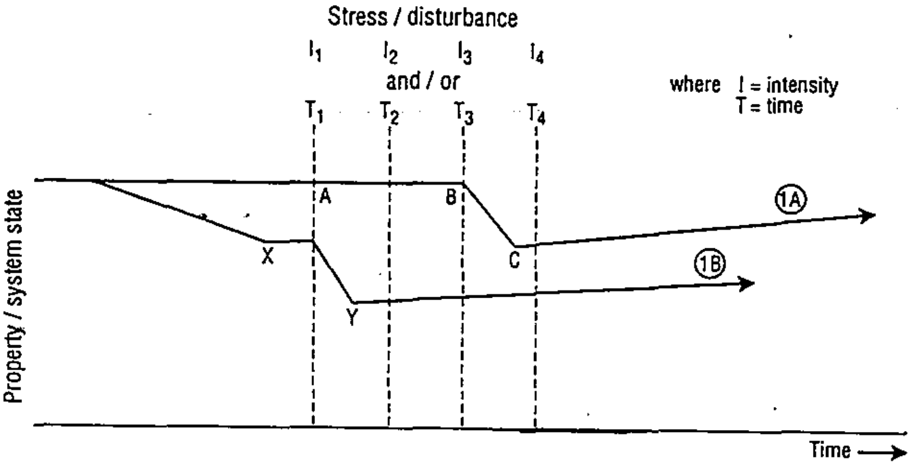
Some of the linkages, however, seem not to be so well known. Some examples are:

- nutrient cycling, including litter production and the role of soil biota (microorganisms as well as termites) in different pasture communities and different vegetation states within these communities, and the role of nutrients and biota in determining pasture composition;
- the role of soil biota in water infiltration and runoff — the various plot studies which have measured runoff under grazing have not documented the changes in biological properties of the soil; and
- the effect of grazing and grazing management practices on soil biota and nutrients. Christie (1979) for example, noted two possible detrimental effects of grazing on nutrient cycling. One was a reduction in litter yield following over-utilization of the vegetation, a change which would also be expected to affect soil biota. The other was a reduction in nutrient uptake due to reduction in the volume of soil exploited by the root system. Other processes are also regarded as being involved, for example, loss of cover is expected to increase soil temperatures and this will also affect the soil biota.

A major gap in understanding, however, is not the individual linkages between particular components, but how the various components all inter-relate, the spatial variation in these processes, and how processes at one location impinge on those in another. Piecing together this type of understanding will take time. Sallaway *et al.* (1993) provide a good example of where our understanding of relationships between components of the grazing system is poor. These authors found that replacement of *Heteropogon contortus* patches by *Aristida spp.* patches greatly reduced infiltration and increased runoff, a change that was associated with differences in macroporosity and possibly linked with biological activity by soil microfauna. They noted, however, that it was impossible to tell whether the change in vegetation was a cause or result of the change in macroporosity.

Also, while spatial aspects of system function have been considered within particular range types, variation in functioning between range and land types also needs to be considered. For example, are soil biota more important in maintaining infiltration and nutrient availability in particular soil types? Another spatial consideration is the way grazing animals utilize different land types and the associated vegetation. In other words, the different linkages need to be considered at paddock scales and not just plot scales. Finally, more attention needs to be given to grazing management strategies and their effects on system function over time and to the corresponding feedbacks on productivity and returns over time. Up until now the focus seems to have been on maximizing product output in the short-term, but often this is associated with higher risks of soil and pasture damage. It may be that alternative strategies can return a greater income over time.

A factor not incorporated in the figure of Hutchinson, but which also needs to be understood, is the role of time. It may be that some processes can continue for limited periods without degradation occurring but continuation beyond a critical time, will result in a threshold to change being exceeded. Similarly, timing of a stress in relation to system condition may also be critical. These concepts are shown schematically in Figure 2. The implications are that experimental work must be sufficiently long to cover potential time thresholds, and also changes in land condition that may be caused by other factors, such as drought, but which will affect thresholds to change. The short-term time-frames of much current research means that the effects of time and changes in land condition are often ignored. In many instances we do not even know how land and soil properties are changing over time, let alone whether any critical thresholds from the point of view of land function, are likely to be exceeded. For example, there have been few, if any, time-series studies of changes in soil carbon (John Carter, pers. comm.).



Property/ system 1A exhibits resistance to change with stress/ disturbance until I_3/T_3 at which point a change of state occurs from which return to the original condition is not possible within the time span of interest. I_3/T_3 represents a threshold in stress intensity or time period of stress.

Property/ system 1B undergoes a natural change in state prior to application of stress/disturbance. In this state the system has no resilience to even the lowest intensity stress of shortest stress duration.

I_1, I_2, I_3 and I_4 represent increasing intensities of stress, and T_1, T_2, T_3 and T_4 increasing duration of stress.

Figure 2. Effects of variation in timing and duration of applied stress or disturbance on resistance and resilience of grazing system properties. If a property reaches a condition from which it is unable to return without the application of remedial treatment, resource degradation is considered to have occurred. (From Williams *et al.* 1993).

Understanding these inter-relationships between grazing and soil/land resources is necessary in order to develop management practices which do not impair landscape function as well as to develop and assess rehabilitation strategies for areas that have become degraded. Some of the current research investigating aspects of inter-relationships between grazing system components is given in Attachment 1.

4.4. Biodiversity

Figure 1 does not consider maintenance of the natural flora and fauna. Retaining the natural biotic diversity within different landscapes is increasingly regarded as part of retaining system function. The effects of grazing on biological diversity other than that associated with wetlands and riparian zones was not a part of this review. It is noted, however, that if the biological diversity of regions are to be maintained, this in itself becomes an objective which needs to be considered in management plans. Meeting the objective will require a knowledge of the biota of regions, areas of particular significance and levels of grazing pressure (including exclosure from grazing), compatible with maintaining the diversity.

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ATTACHMENT 1 — CURRENT AND PROPOSED RESEARCH

Soil — vegetation inter-relationships

Distribution of Roots Among Neighbouring Plants of a Tussock Grass Species in a Tropical Grassland

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Background: Distribution of root systems of perennial grasses within the soil profile is one of the key factors to plant productivity and survival. Root distribution influences acquisition of water and nutrients needed for photosynthetic activity, growth and development of physical structures, and production of new propagules.

Use of the soil profile by root systems of important tussock grasses is not widely understood. It is not known, for example, whether tussock grasses have roots inhabiting large portions of the interspaces between tussocks. An additional knowledge gap is the effect of landscape degradation on use of the soil profile by perennial bunch grasses. Characterizing the area of soil profile occupied by roots of grasses will be important in understanding resource use by grasses and the dynamics in degradation and recovery of pastoral lands. It will also be an important focal point for modelling landscape productivity and plant growth. Data collected in this study will allow examination of whether tussocks of perennial grasses extensively utilize soil resources within interspaces between plants.

Objective: To define the micro- and meso-scale spatial distribution of roots of neighbouring plants of tussock grasses.

Methods: materials to be analyzed will be collected from 3 different pasture state classes with different levels of utilization, within paddocks at the Cardigan experimental site, near Charters Towers. State classes included will represent a range of different stages in the desertification of landscapes in Queensland.

Sampling will be conducted between pairs of tussocks of the predominant species *Bothriochloa ewortiana*. Soil cores to 1 m depth will be collected in a transect from the center of a tussock to the center of the neighbouring tussock. Cores will be taken at: 1) tussock centers; 2) tussock edges; 3) center of inter-space distance; 4) between interspace center and tussock edges. Collected soil cores will be divided into 6 depths: 0-10 cm; 10-20 cm; 20-40 cm; 40-60 cm; 60-80 cm; and 80-100 cm. Below 40 cm, root distribution under native perennial tussocks is not known. A preliminary survey indicated that the highest rooting activity occurred in the top 20 cm, and moderate amounts were present from 20-40 cm.

Sampling will be conducted to examine plant responses to environmental stresses to see whether the distribution of roots expands or contracts into interspaces with changes in abiotic factors. Small exclosures will be established around sets of plants, and two different factors will be manipulated: 1) soil moisture level; and 2) defoliation. Root dynamics within the wet and dry seasons will be determined. Root characteristics (length, surface area, size class distributions) will be measured with scanning imagery equipment and biomass (g dry matter) of samples will be determined.

Additional soil materials of the upper 5 cm of the soil profile will be collected at each location along the transects for analysis of soil microbial biomass.

and recognized, and programs developed which have the capacity to meet the various needs of producers.

6.3 Identified knowledge gaps and recommended research

Knowledge gaps and recommended research are discussed under headings that relate to the different topics reviewed in this report. The exception is '*Uptake of information*' which has not been covered in previous chapters.

6.3.1. Uptake of information

The terms of reference for this review included identifying critical gaps in uptake of knowledge. Major gaps identified are listed below.

6.3.1.1. Overgrazing

Trials with exclosures have shown that even during droughts, low stocking rates can reduce grass cover to below that which would occur naturally and lead to higher runoff, sediment and nutrient losses. Grazing management following drought has also been highlighted as a particular problem though there has been no R&D to help determine appropriate management practices that reduce degradational processes. Water, soil and nutrient losses not only result in short-term reductions in biomass but are probably also reducing the long-term productivity of the land, although the time-frame necessary for long-term productivity decline to become apparent has not yet been satisfactorily quantified. There is no doubt, however, that overgrazing is contributing to decline in the productivity of soil resources. Overgrazing is defined here as the utilization of resources (through both grazing and trampling/trafficking) past thresholds which lead to the initiation of undesirable processes.

Another point to be considered is that while droughts can result in the initiation of processes leading to loss of land productivity, these are naturally occurring phenomena over which we have no control. Degradational processes initiated by grazing management practices can be controlled and prevented. There is no logic in regarding degradational processes resulting from grazing as not an issue because similar processes may be initiated naturally. The aim of grazing management is to ensure that utilization of the resource is within its productive capacity and that degradational processes are not exacerbated.

Discussions during this review indicated that there is poor awareness within the grazing industry as a whole, of the land degradation that is occurring as a result of stocking strategies. It seems that often any land degradation that is acknowledged is generally attributed to drought rather than a combination of drought and stocking management. There is also the view that the land is resilient and will "come back". These are obviously perceptions that hinder the on-farm development of profitable and sustainable grazing systems, recognition of a problem being the first step to its solution. A critical need is therefore to increase the awareness and understanding within the grazing industry of the land degradation being caused by overgrazing.

Other factors identified by various people as hindering the adoption of more sustainable practices are:
- lack of data to show that profitability and sustainability are compatible and counter the belief that they are not;
- insufficient information on how management to maintain resources can be integrated with marketing and herd replacement strategies to allow an enterprise to be profitable in the longer term; and
- external pressures, such as loan repayments, and taxation arrangements that favour particular practices.

The first two issues are taken up under the specific recommendations below. External pressures need to be acknowledged as constraints to the adoption of ecologically sustainable grazing systems and included among the constraints identified as part of the Subprogram 2 strategy for addressing key issues (see Chapter 1).

6.2.1. Pasture types versus land types

- It is recommended that NAP3 consider land as well as pasture differences in the design of research and monitoring programs.

Pasture communities traditionally have been used to distinguish the various grazing lands in northern Australia. This is understandable given that pasture is a major resource for the industry. Land degradation and productivity, however, are determined by other characteristics of the land — climate, geology and geomorphic history, topography, and regolith and soil. It is therefore essential that these features are taken into account in the design of research and monitoring programs that aim to improve sustainability by reducing resource degradation. This will mean, for example, that research and monitoring programs will need to be located in representative land systems and types rather than representative pasture types.

6.2.2. Monitoring

- Indicators identifying thresholds and changes in land processes need to be developed.

A review of monitoring programs and methods, including those for on-property use, was not undertaken as part of this project. It is apparent from research on landscape processes, however, that indicators identifying thresholds and changes in land processes are needed and that monitoring should not be restricted to only monitoring vegetation or soil condition. What we term land or soil degradation are changes in the condition of the land or soil (eg, loss of soil structure, loss of soil depth, decrease in soil pH) that result from change in various processes. In order to prevent degradation from occurring, it is necessary to understand the inherent processes involved and to be aware of their occurrence before degraded states are reached. Indicators of processes will be required to prevent degradation occurring and will be more useful than indicators of a final degraded state.

6.2.3. Best practice

- For the north Australian beef industry, "best practice" needs to be generic and defined in terms of principles (eg, sediments and nutrients should be retained locally and not lost to the drainage network) rather than in terms of specific practices (eg, retaining a specific percentage ground cover). There also needs to be continual monitoring of recommended practices to ensure that they are achieving the desired results and that they are consistent with new research findings.

There is a current trend within industry to define best practice. The extensive area covered by the north Australian beef industry and the consequent enormous variation in land systems (including climate) means that standardized management practices for northern Australia cannot be developed. It is therefore appropriate that best practice is defined in terms of principles, although these can be translated into specific practices designed to suit the local land systems, where graziers require more prescriptive advice.

6.2.4. Education and awareness programs

- It is recommended that the different needs of various groups within the industry be identified/ recognized and appropriate extension programs developed to address these specific needs.

The grazing industry consists of a diverse group of people with a range of management skills. Some graziers, for example, can use principles and adapt them to their own situations while others need prescriptive guidelines. Some graziers already have a good knowledge of the biophysical and economic systems with which they are dealing while others have very little. These differences should be identified natural conditions compared with those where the land is used for grazing. The alternate view is that the effects of various grazing industry practices, both on-site and downstream, need to be identified and compared with the natural condition, and an assessment made of the extent to which degradational processes can be reduced.

The view adopted here is that a prime and proper concern of the grazing industry is on-property management to maintain and rehabilitate the land and pasture resource. The need to identify the effects on land and water resources that various grazing management practices are having, however, is also regarded as important, as is the need to identify processes under natural conditions. There are several reasons for adopting this approach.

1. There is a growing requirement from the community that our agricultural products are "safe" from a human health perspective and are produced in a way which does not cause degradation of the environment. With continuation of current trends, a marketable and competitive product will depend on the grazing industry being able to show that its activities are not having adverse environmental effects. The industry will need to fund work to identify the effects that it is having, particularly off-site, so that these can be remedied, and/or to demonstrate that off-site effects are not significant. It was noted during this review that the sugar and cotton industries are far more active in such research than is the beef industry.

2. It is suggested that by taking a responsible and proactive role with respect to its off-site effects, the industry will be in a stronger position than if it chooses to ignore such issues. If the industry does not take a responsible role, government intervention and regulation is more likely, particularly if downstream users and other community groups are concerned about the effects the industry is having on them. A good example of the benefits that can accrue from work not initially seen as relevant to the industry, is the tree monitoring studies carried out by Dr Bill Burrows. This work has shown that the increase in woody vegetation in northern grazing lands has lowered Australian greenhouse gas emissions by 15-20% and such information can now be used to advantage by the industry. It needs to be recognized that we cannot always know the benefits of particular lines of research in advance.

3. It is only by knowing the effects that particular practices are having in particular environments, that any deleterious practices can be remedied. It is important that identifying deleterious practices is seen as an opportunity by the industry, rather than as a criticism. A popular view is that extensive grazing is one agricultural industry that is inherently compatible with maintenance of our land and water resources, including their biotic diversity.

6.1.4. Appropriateness of research for funding by NAP3

All recommendations made are regarded as relevant to NAP3. An issue not considered in making the recommendations, however, is whether other research organizations or funding bodies, would be more appropriate to take responsibility for some recommendations. There are two reasons for this. One is that this review is seen as providing an information base to research groups and agencies beyond the MRC. The second is that many government research agencies are currently in a considerable state of flux and their objectives and roles are not clear and well defined. The view of the author is that some activities, such as monitoring, would best be supported by state government agencies as these programs need to be long-term and government organizations should be in the best position to take the long-term perspective. It seems that this is not the case at present. Until the roles of various organizations are clearer, it is premature to assign areas of responsibility to them.

6.2. Principles recommended for adoption by NAP3

Given here are general recommendations which pertain to the orientation of NAP3, and the reasons for the recommendations.

6. RECOMMENDATIONS

This chapter provides recommendations for new research relevant to improved resource management, that might be appropriately funded by Phase 3 of the MRC's North Australia Program. The first sections of the chapter discuss issues and gaps identified during the review, including from discussions with research personnel, and at the workshop held by the MRC early in August. It also gives the recommendations presented for consideration at the workshop. This workshop was held specifically to allow input by research and producer groups on the draft report and its recommendations (see Appendix 2 for a list of workshop attendees). The last section of the chapter gives the priority recommendations for research and the guiding principles that were developed at the workshop.

6.1. Issues considered in making recommendations

6.1.1. The need for uptake of current knowledge

Improved management of the northern Australian grazing lands cannot wait until our knowledge of the resource base and understanding of the underlying processes are more developed. Sufficient is known about the deleterious effects of some grazing management practices, particularly high herbage utilisation rates, to initiate programs to try and ensure that such practices do not occur. In making recommendations for such programs, it is necessary that variation between different land types is recognized. Relationships between grazing management and soil and vegetation response that have been developed for particular climatic regions and land types cannot necessarily be extrapolated and transferred to others. Consequently, it is not possible to recommend management practices and strategies that will be applicable to the northern grazing industry as a whole, or to particular agroecological regions, other than in broad general terms.

6.1.2. The need for further research

Having acknowledged the need to apply current knowledge now, however, it is also very important that we do not regard our current understanding of the land, how it is functioning and its response to management, as adequate. While full use is not being made of current knowledge and this must be addressed, there are also many aspects of land function that are not understood. Management and monitoring strategies need to be underpinned by sound science and the concern has been expressed that in many areas the science is not keeping sufficiently ahead of the requirements for practical information. Two examples are given as illustration. One is the view that the ecological techniques underpinning current vegetation monitoring are not properly understood at the scientific level. A second is the opinion that the "downs" and alluvial plains of the Barkly Tableland contain essentially two different pasture types that reflect differences in geomorphic processes. The alluvial plains carry predominantly annual grasses while the "downs" support predominantly Mitchell grass pastures. A commonly held view, however, is that the annual pastures have lost their perennial component and are indicative of pasture deterioration. It is clearly critical to management that our understanding of the cause for variation in pasture types is correct.

6.1.3. Improved land management versus the need to understand off-site effects

There is a difference of opinion both within the research and grazing industry communities, over the need to define and quantify the effects the grazing industry is having on land and water resources. One view is that implementing conservative management will ensure that the degradation caused by grazing is the minimum that can be achieved within a productive industry and that there is no need to concentrate on the effects of particular practices or to distinguish between processes and fluxes under

3. Making our understanding of pasture ecology relevant to each land type

- Current research is helping to distinguish the effects of grazing, climate, and fire on condition and trend of native pastures. However, for many land types there is little agreement on what pasture species are most desirable or on what pasture composition is possible under different conditions. In co-operation with sub-catchment groups, we will locate and sample areas on each major land type that have had different grazing pressures, due either to fence-line effects or to distance from water. From this, we will deduce the relevant indicator species for assessing range condition. Small exclosures will be used to measure primary production on selected patches within each land system, to demonstrate the effects of land condition and recent utilisation level on forage growth.
- A pragmatic approach to assessing condition and trend will be developed and road-tested with the sub-catchment groups. In combination with assessments of pasture growth and standing crop, this will allow integration of pasture-based information into tactical decisions on stock numbers.

4. Carrying capacity estimates at the paddock level

A method for assessing carrying capacity for each land type/land condition/tree density combination will be developed based on estimates of forage production (from part 2 above) and "safe" utilisation levels; the latter will correspond with data obtained from researchers, extension staff, and sub-catchment groups. This follows the approaches developed for Queensland's eucalypt woodlands (Scanlan *et al.* 1994) and mulga shrublands (Johnston *et al.* 1996). Providing paddock-scale estimates of carrying capacity also requires accounting for patterns of pasture and landscape use due to selective grazing, preferential use of land systems, location of watering points, topography, and location of shade. The assessment method will be tested against producer experience and property records.

5. Delivery of guidelines, training and decision tools

Grazing management guidelines and decision support tools will be produced that meet needs for (1) development of sustainable whole-property grazing plans and (2) variation of grazing pressure in response to changing vegetation condition. Specific products will include:

- Grazing management manuals (and associated training workshops) for each sub-catchment that provide guidelines on carrying capacity, tactical stocking decisions, and measurement and interpretation of land condition.
- Decision-support software, and equivalent paper-based versions, for calculation of safe carrying capacities and short-term variation in stocking pressure.
- A database which links land resource information (land systems, soils), ecological condition, woody plant cover, and pasture production.
- Training workshops in grazing management offered as part of, or in addition to, property-management planning activities

Project duration: July 1997 - July 2000

Locality: Burdekin, Fitzroy, and Burnett Catchments

Sponsors: NHT, Queensland Department of Natural Resources and Queensland Department of Environment runoff/sediment sources, linking to DTM and routing runoff/sediment through paddocks or landscapes. For Dotswood, the basis for this is the survey and compilation of a 1:50000 soil unit map.

Sustainable grazing management for eastern Queensland river catchments (proposed project)

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Rationale: Grazing management is the major land management issue threatening the sustainability and bio-diversity of the black speargrass grazing lands in the Burdekin, Fitzroy, and Burnett River catchments. In many cases, unrealistic expectations of carrying capacity, together with failure to adjust stock numbers in response to availability and condition of pasture, have contributed to chronic shortages of forage, loss of desirable perennial grasses, increased bare ground, and increased density of native and exotic trees and shrubs. Consequently, the safe carrying capacity, bio-diversity, and habitat value of much country is being eroded. While the problem is complex, being related to many social, climatic and market factors, there is no doubt that improved grazing management and a greater level of "land literacy" are central pre-requisites for sustainability and maintenance of bio-diversity. Information on soil types, pasture growth, and effects of grazing is available for the catchment areas but there has been no synthesis into sound, credible guidelines for pro-active grazing management. This is a major impediment to improved industry performance in grazing land management.

Objectives:
To develop and promote sustainable grazing management in the Burdekin, Fitzroy, and Burnett River catchments by:
1. Collating and integrating technical and landholder knowledge on a range site basis.
2. Developing and road-testing methods for assessing carrying capacity, and condition and trend, of land types (range sites) in each catchment.
3. Increasing awareness and understanding of land condition and its relationships with land management, bio-diversity and productivity ("land literacy") amongst landholders and agency staff.
4. Supporting whole property planning via provision of credible grazing management guidelines.

Methods:
1. Identification of a range site framework: developing land literacy
Necessary tasks:
- obtain regional Land Resource Data Base (LRDB), and overlay with geology, vegetation, and cadastral data.
- assess use of LRDB for identifying land types within paddocks.
- assess need to distinguish between land types on the basis of the types and amounts of forage production (see part 2 below).
- record producer perceptions of land types and determine correspondence with LRDB land units.
- road-test range site framework with sub-catchment groups.
- link to regional land resource descriptions, through DroughtAlert project.

2. Operation of GRASP on a land-unit basis
GRASP is a computer model for simulating forage production from native pastures. It has already been successfully used at land system and regional scales. To operate on a range site basis, the following activities are required:
- identify functional characteristics of soils and set parameters for land units.
- establish reference exclosures on a representative sample of land units and demonstrate ability of GRASP to adequately match real-world data over 2-3 growing seasons.

Soil unit mapping — Dotswood property of the Townsville Field Training Area (TFTA)

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PMB, PO,
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Objective: To map soil units of the Dotswood property at 1: 50 000 scale

Land capability assessment, including carrying capacity and susceptibility to degradation

Desert Uplands — land condition assessment and on-ground works

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Background: The Desert Uplands Buildup and Development Committee, together with the Departments of Environment and Natural Resources, have identified an urgent need to have a comprehensive, accurate assessment of the condition of the land within the Desert Uplands region. Such information will allow:

1. the location, extent and causes of severe land degradation to be identified;
2. priorities to be established for restoring degraded land;
3. a revision of land management practices for specific land types; and
4. the identification of land that is suitable or unsuitable for development.

Objectives: The aims of this project are to develop an appropriate method for assessing land condition in consultation with the Desert Uplands Buildup and Development Committee and officers of government agencies. The method will take into account cleared versus uncleared land and the condition of the soils, pastures, tree canopy, fauna habitat and natural biodiversity. It will involve a combination of field work, remote sensing (satellite imagery) and consultation with Landcare Groups and individual landholders. The final report will identify the nature and extent of degradation associated with each land type together with a rating for the susceptibility of each land type to various degradation processes. Data entry into a Geographic Information System (GIS) will be at a scale of 1: 100 000 but the final map will be at a scale of 1: 250 000.

Proposed project duration: July 1997 - June 2000

Dryland Farming for Catchment Care Program — catchment scale erosion hazard

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Objective: to conduct catchment scale assessment of erosion hazards in some of the rangelands west of Townsville (Balfes Creek Catchment; Dotswood/TFTA. The approach includes point scale assessment of will be surveyed separately. The final report will be in the form of maps at 1:250 000 and a database with land resource information at 1:100 000.

Proposed project duration: July 1997 - June 2000

Enhanced Natural Resource Information System, Balonne-Maranoa District (proposed)

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Background: The Balonne-Maranoa district is poorly served by relevant and reliable information on land resources; only a very broad land system study at nominally 1:500 000 scale is available, with some larger scale information for the Roma area and for the St George irrigation area. Despite considerable land use change and the potential for agricultural and other development, useful information on current land use, land condition and land suitability for a variety of uses is not available or easily accessed. The South West Strategy and Balonne Shire Council have requested that the DNR provide more reliable and appropriate information for land use planning in the district. The NRMS funded Murray-Darling Soil Information Strategy has determined that the Balonne-Maranoa area is a priority for land resource assessment and would facilitate completion of a consistent and complete coverage of information for the Queensland section of the MDB at 1:250 000 scale. Current information is inadequate for land use planning, land management decision support, carrying capacity assessment and rural reconstruction.. The DPI/DNR Business Plan for land resource assessment suggested that 1:250000 scale information was a priority for the area.

Objectives and products:

- The project aims to produce a comprehensive natural resource information system for the Balonne/Maranoa to provide a basis for land use planning and sustainable resource management.
- Central to the project will be a comprehensive study of land resources including soils, landforms, regolith, land use and condition and trend of the Balonne and Maranoa Catchments at 1:250 000 scale, complemented by nested larger scale key area studies (1:100 000 in dryland cropping areas and 1:50 000 for the irrigation areas of the Balonne floodplain).
- New and enhanced technologies including the use of digital terrain models, remote sensing, quantitative land evaluation methods linking crop production models with spatial data bases, and explicit soil-landscape modelling within GIS will be incorporated to improve the reliability and usefulness of the information and to enhance the efficiency of survey.
- Information will be readily available and integrated in an advanced geographic information system, and available in a variety of thematic forms and media via the Internet, reports, a manual detailing management guidelines, maps and GIS coverages in formats useful to land users, planners and managers, complemented with field days and workshops.
- Maps will include: soils and soil properties, land suitable for dryland agricultural uses and pastures, irrigated agriculture where appropriate, agricultural land classes for town and shire planning (Good Quality Agricultural Land), current land use and degradation state and potential.
- Reference sites for long term monitoring of land condition and to extend information to land managers will be established.

ATTACHMENT 1 — CURRENT AND PROPOSED ASSESSMENT PROGRAMS AND PROPERTY EXTENSION

Land resource survey

Catchment management in the desert uplands

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Background: The Desert Uplands of central Queensland are the remnants of an extensive Tertiary surface, stretching from Pentland in the north, south to near Blackall. The region is dominated by sandy infertile soils prone to rapid degradation if over-utilized. In the northern part of the region there are extensive internal drainage basins containing Lake Buchanan and Lake Galilee. Both are considered to be of State significance for waterfowl.

Due to the relatively low agricultural productivity of the region there has been little attempt to define the regional resources in detail or to clearly define management strategies that would enable their sustainable use. Recent land use changes, including extensive clearing near Lake Galilee, and increasing land degradation in both catchments, suggest that detailed catchment management plans should be prepared if the natural resources are to be sustained.

Objectives: The objective of this project is to map the land resources of both catchments (6-7,000 km^2) at 1: 100 000. Some representative sites will be selected from air photo interpretation, for soil sampling. Sampled soils will be sent for analysis of chemical and physical properties.

Project status: two maps have been published and the final report is being prepared for publication. The report contains three parts: Part 1 contains the land resource data; Part 2 contains the technical details and Part 3 a proposed management plan. The draft catchment management plan identifies the main issues, highlights the limitations of different land types and recommends appropriate management practices. The draft plans are the basis for a new project proposal for NHT funding (Lake Buchanan - Lake Galilee Catchment Management Plan: Implementation) which is seeking funds to explain the plan to, and discuss the plan with, a broad section of the rural community and officers of lead government agencies.

Desert Uplands land resource mapping

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Objective: To produce a land resource map that is consistent for the whole Desert Uplands bioregion, at a scale that relates to individual properties, and which can be used to adjust land use and land management practices according to the capability or limitation of different land types.

Methods: All existing land resource studies will be updated to the required level of accuracy, scale and detail, using a combination of remote sensing and field work. Any areas without land resource information

Payne, A.L., Kubicki, A., Wilcox, D.G. and Short, L.C. (1979). A report on erosion and range condition in the West Kimberley area of Western Australia. Technical Bulletin No. 42. (Department of Agriculture of Western Australia: Perth).

Rogers, L.G., Cannon, M.G. and Barry, E.V. (in press). Land Resources of the Dalrymple Shire. (Queensland Department of Natural Resources: Brisbane).

Shields, P.G., Smith, C.D. and McDonald, W.S. (1996). Agricultural land evaluation in Australia: A review. (Australian Collaborative Land Evaluation Program: Canberra).

Tothill, J.C. and Gillies, C. (1992). The pasture lands of northern Australia: Their condition, productivity and sustainability. Occasional Publication No.5. (Tropical Grassland Society of Australia: Brisbane).

van-Cuylenburg, M. (1996). Accelerated land resource survey and capability assessment in the Victoria River District, NT. *ACLEP Newsletter* 5(1), 12-4.

Van Vreeswyk, S. (1996). Rangeland resource surveys in Western Australia. *ACLEP Newsletter* 5(1), 8-9.

The primary aim of these assessments has been to provide individual property managers with land capability information at an appropriate scale to guide property development and management.

Cattle properties in both Central Australia and on the Barkly Tablelands are large, typically around 1500-5000 km^2 in the Alice Springs district and 5000-14 000 km^2 on the Mitchell grass downs of the Barkly Tableland. Fencing on these properties has increased in recent decades, primarily in response to brucellosis and tuberculosis disease eradication programs, but the typical management unit on these properties is still the area lying in grazing distance of a water point. This is usually 8 km, with the total grazing area covering about 200 km^2. Most property mapping has therefore been at a scale of 1: 1000 000 to allow the land capability of management units to be determined. At 1: 100 000 scale, mapping units can describe relatively uniform tracts of country in terms of landform pattern, soil type and vegetation community. Experience has shown that mapping at scales coarser than 1: 100 000 fails to identify areas of land susceptible to degradation. Emphasis is placed on air photo interpretation with detailed descriptions at a density of 6 sites/ 100 km^2. Satellite imagery interpretation has been trialed as a cost effective method of small to medium scale mapping but has had disappointing results at 1: 100 000 scale, particularly on the Barkly Tablelands.

The mapping program has found that the pastoral industry is receptive to appropriate resource information and that demand for mapping by property managers currently exceeds the rate of coverage. The use of on-property GIS systems is also being investigated.

5.2.3. Land resource survey and assessment in Queensland

There has been a long history of land system mapping and land resource assessment in Queensland. Until recently, the Queensland Department of Primary Industries had major responsibility for such programs. Resource mapping and assessment now has a more regional structure although the Enhanced Resource Assessment Program within the Department of Natural Resources has state-wide cover. This program aims to evaluate new techniques for resource mapping and assessment.

5.3. Resource condition assessments

In addition to land surveys, the aim of which is to map land types, several land condition surveys have been carried out. The aim of these surveys is to assess the condition — degree of degradation — usually of the soil and/or vegetation (pasture). The most extensive of these surveys was that undertaken by Tothill and Gillies (1992) which assessed pasture condition across northern Australia. These authors graded pastures into one of three groups: A: 'desirably sustainable'; B: 'deteriorating'; and C: 'degraded'.

Within Queensland, a land condition survey of the Dalrymple Shire has recently been completed (Rogers *et al.* in press) and several resource condition surveys have also been undertaken in the Kimberley region of Western Australia (eg. Payne *et al.* 1979).

5.4. Other current land survey and resource assessment projects

Attachment 1 lists other projects involving land resource survey and mapping that are not covered by the state programs.

References

Grant, R. (1996). Facing a dilemma of scale — land resources assessment for the management of Central Australian rangelands. *ACLEP Newsletter* 5(1), 5-6.

The land survey information has also been used to assess the representativeness of existing nature conservation reserves in at least some areas for which surveys have been undertaken. One such assessment has found that the reserves are dominated by types of land least suitable for pastoralism and areas preferred for grazing are poorly represented, if at all. Land survey information is also being used in the rangelands to locate strategic vegetation monitoring sites across the region on the basis of both representativeness of land types and susceptibility of the land to degradation.

5.2.2. Land resource survey and assessment in the Northern Territory

Land resource surveys in the Northern Territory are administered by the Lands, Planning and Environment Department. Both land system (1: 100 000 scale or smaller) and land unit (1: 100 000 to 1: 10 000 scale) are being undertaken in the rangelands. The goal of the NT land resource survey and assessment program is to identify the resources of the Territory, evaluate their capabilities for sustainable use and monitor their status. In recent years, the National Landcare Program has helped fund part of the program to accelerate acquisition of land capability information for Property Management Planning. Priorities for this mapping program have been determined on the basis of existing map cover and the known susceptibility of areas to degradation, and include the Victoria River District, the Barkly Tablelands and the Alice Springs region (Shields *et al.* 1996).

5.2.2.1. Land resource survey and capability assessment in the Victoria River District, NT

(From van-Cuylenburg 1996)

A program of land resource surveys and capability assessments has been undertaken in the Victoria River District (VRD) of the Northern Territory since 1990, with support from the National Landcare Program. The program's prime objective is to map, describe and evaluate pastoral areas and to extend this information to landholders. The base information allows the development of property plans which includes identifying areas degraded through inappropriate management and planning their rehabilitation.

Fieldwork in the program is designed to map resources on a property basis with fifteen properties and a total area of 60 000 km^2 mapped by the beginning of 1996. Information is collected on the landforms, soils and vegetation and sites are grouped to form the unique vegetation community of each land unit. The five most dominant species within the grasslands community has the five most dominant species listed with each species given a rating of one to five, where rating is based on a system incorporating nutrition, digestibility and palatability. Pasture rating maps can be produced though care must be used in using a map produced in one year, as a guide in subsequent years due to pasture production being dependent on seasonal rainfall.

Historically, the Victoria River District has tended to be overstocked and overgrazed, particularly where covenants required minimum stocking rates and where uncontrolled grazing caused extensive degradation along waterways. Land unit mapping in the VRD has also assisted in the production of erosion hazard assessments for each land unit, which allow areas of the landscape prone to sheet erosion to be identified.

Surveys have involved close liaison with property managers and land unit descriptions have been produced in layman's terms, where all soils and vegetation are referred to by their common names. The maps, along with the pasture and erosion hazard ratings, have increased the pastoralists knowledge of the land resources of their properties and have been used in the development of more sustainable land use practices.

5.2.2.2. Land resource assessment in Central Australia and Barkly Tableland

(From Grant 1996)

Ecologically-based land resource assessments of central Australian properties began fifteen years ago, with additional resources to accelerate this work being committed by the National Landcare Program over the past five years. This has allowed extension of the program to the Barkly Tableland.

5. LAND RESOURCE SURVEY AND ASSESSMENT

Land resource surveys and assessment have been, and are being, carried out within the rangelands of Western Australia, the Northern Territory and Queensland. This section briefly comments on some of this work and the use that is being made of it.

5.1. Rationale for land resource mapping

While the fundamental processes of material (water, nutrients, etc) and energy transfer operating in all landscapes are the same, their rates, extent and interactions are determined by the particular landscape in question — its climate, geology and geomorphic history, topography, regolith and soil, and vegetation. Landscapes with similar characteristics tend to have similar process rates and interactions, and hence potential for productivity as well as susceptibility to deterioration. Land systems, and the land units which comprise them, therefore provide a useful basis for planning land management, monitoring programs and research as they group together areas of land which tend behave in a relatively similar fashion. In addition, in rangelands where there is generally relatively little alteration of the native vegetation, vegetation structure and species composition are usually well correlated with the other land features. As a result, land systems also offer a useful basis for identifying vegetation and habitat diversity. Understanding vegetation—land type inter-relationships can also have important implications for land management. For example, it is important to know whether differences in vegetation composition and structure are the result of differences in land type or grazing management (stocking rate, use of fire).

5.2. State land resource survey and assessment programs

A full review of land system survey coverage and other resource mapping programs (including flora and fauna surveys) in the northern Australian rangelands has not been undertaken. Given here is some information on land survey work that is being done and on use being made of this information.

5.2.1. Land resource survey and assessment in Western Australia

(From Van Vreeswyk 1996)

Land resource inventory and assessment surveys are carried out by a combined team from Agriculture Western Australia and the Department of Land Administration. The objective of land surveys in the rangelands of Western Australia is to map and comprehensively describe their biophysical resources and to evaluate soil and vegetation condition. The resulting maps and reports are intended primarily for land managers, land management advisers and land administrators. They contain information useful for planning land management at sub-catchment, lease or paddock scale and also for locating land types of particular land use or conservation value.

Using land system information to plan pastoral management is facilitated by a companion report which provides, for each property, information on its land systems, their range condition and suggested carrying capacity. There is also a 1: 100 000 scale map of land systems occurring on the property that can be used by pastoralist for planning grazing management and the repositioning of fencing and waterpoints which will ensure that management strategies are specific to the pastures within each management unit and that overgrazing of preferred pastures or under-utilization of poorer pastures is avoided. The assessments of range condition allow pastoralists to identify degraded areas and plan their rehabilitation.

Coping with rainfall variability: Grazing management strategies for seasonably variable tropical savannas

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Core project objectives:
1. Assess and demonstrate the ability of different grazing strategies to copy with rainfall variability in terms of their effects on animal production, economics, pasture condition, soil loss and biodiversity.
2. Develop, in conjunction with graziers, practical and sustainable grazing management strategies to copy with present and future rainfall variability.
3. Promote adoption of these strategies through demonstration and direct links to PMP, LCD and local Landcare/grazier groups.
4. Synthesise available data into simulation models to allow extrapolation to a range of different environmental and economic conditions.

Subproject objectives:
Biodiversity: To determine the effects of different grazing management strategies on faunal and floral biodiversity.
Plant population processes: To determine the effects of different grazing management strategies on major plant population processes such as mortality, seed production and recruitment of important pasture species.
Soil and nutrient loss: To determine the effects of different grazing management strategies on soil loss and nutrient discharge into catchments.
Dietary selection and foraging behaviour: To determine the effect of different grazing management strategies on dietary quality, intake and foraging behaviour in cattle.
Patterns of plant defoliation: To determine -
(i) the effect of selected grazing strategies on the frequency and intensity of defoliation of individuals of selected plant species through the grazing season;
(ii) the effect of landscape position on the frequency and intensity of defoliation, and
(iii) the effect of the above variables on plant survivorship and mortality.
Remote sensing to assess herbage availability: To investigate the use of, and possibly develop, remote sensing as a tactical tool to estimate herbage availability at the paddock scale.

Location: Wambiana Station, approximately 100 km S of Chartres Towers, in the Burdekin Catchment, in the semi-arid tropical savannas of northern Queensland.

Climate — soil, vegetation, disturbance inter-relationships

The determinants of land degradation in wet/dry tropical savannas

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Objectives:
1. To define the relationships between soil type, mean annual rainfall and the vegetation communities within the wet/dry tropical savannas of north-western Australia, using existing data held on geographic information systems.
2. To apply two disturbances (exclusion of stock, severe defoliation of grass layer) at a series of selected sites along the rainfall gradient south of Darwin, and compare with ambient conditions by measuring the rate, degree and processes of land degradation and/or recovery.
3. Develop an improved understanding of the processes of land degradation in the wet/dry tropical savannas, and to formulate a rating of soil/rainfall/vegetation associations based on risk of degradation.
4. Make the results and interpretations available to management and research agencies across northern Australia, with a focus of assisting development of policies and guidelines for land use and for the monitoring of changes in land condition.

Methods:
1. The relationships between mean annual rainfall, soil type and the composition, height and cover of major woody and herbaceous species will be determined for Northern Territory vegetation north of 18 degrees S. The data already exists on GIS.
2. A matrix of experimental sites will be established along the rainfall gradient between Darwin and Kalkarinji, and on a range of soil types. At each site, three treatments will be imposed: (a) stock excluded; (b) ambient conditions; and (c) artificial clipping of herbaceous vegetation. A range of soil and vegetation parameters will be measured to assess the degree and processes of land degradation across the range of soil types and rainfall levels.

Sponsors: Land and Water Resources R&D Corporation and Conservation Commission of the NT

Grazing — vegetation — soil inter-relationships

Foraging behaviour in tropical grasslands

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Objectives: To measure herbivore resource use at a landscape scale (422 ha paddock) and to relate this to vegetation response.

Location: 30 km NW of Charters Towers, north-east Queensland

N_2O emissions from savanna soils (aspects of N cycling)

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Proposed Study: Description of the Desertification Process in Soils of a Tropical Grassland

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Background: spatial variation in soil physical and chemical properties within native plant communities can be high, with organic matter, pH, and different mineral element concentrations varying by an order of magnitude over < 5m. Such variation has been shown to be related to changes in plant densities, and shifts in species distributions. Similarly, nutrient cycling in disturbed and natural ecosystems are spatially variable processes, and this variability alone may affect the structure of plant communities, potential states achieved, or transitions followed. It has been suggested that availability of limiting nutrients and the spatial patterns in availability of these nutrients, are critical components (though largely unquantified) of plant community structure.

Objective: the aim of this study is to use sophisticated analytical techniques to model spatial changes of important soil nutrients and plant biomass in tropical grasslands, associated with different vegetation states.

Methods: A multi-phase study will be undertaken to assess changes in nutrient distributions in Queensland plant communities at fine scales of resolution, in response to different levels of desertification. Each phase will focus on different surface elements, ranging from individual plants, to small patches. Results attained will be applied in an additional phase to interpolate distributions at a medium-scale level (paddock or part of a paddock).

Phase I. Response of individual plant root systems to different levels of landscape degradation.

The objective is to characterise the vertical and lateral distribution of the roots of important tussock grass species, associated with different vegetation states. Materials to be analysed will be collected from three different state classes with different utilization rates in experimental paddocks within the Cardigan site, near Charters Towers.

The vertical and lateral distribution of root biomass within plant-soil polygons of the three predominant grass species *Heteropogon contortus, Chrysopogon fallax* and *Bothriochloa ewortiana* will be examined. The size of the polygon to be described will depend on state condition of the paddocks, and mean inter-plant spacings. The initial proposal is that a polygon will be the tussock, plus 25 cm in the four cardinal directions. Root distributions will be determined by sampling within a 2-dimensional grid originating at the center of plants, and extending outwards to the edge of the root distribution profile. This sampling scheme will focus on accurately defining variance in the zones of maximum rooting activity (eg. 0-90 cm depth, and center to ~ 20 cm outward). The majority of roots will likely occur in the upper 50 cm.

Root characteristics (length, surface area, size class distributions) will be measured with scanning imagery equipment and biomass (g dry matter) of samples will be determined.

Spatial Distribution of Soil Resources Around Perennial Tussock Grasses in a Tropical Grassland

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Background: It has been proposed that scarce or limiting resources in semi-arid and arid regions are patchily distributed across the landscape, and concentrated in "fertile" patches that comprise a minor segment of the total land area These resource islands supposedly form by aeolian and fluvial deposition of materials in micro-sites protected by standing organic matter of plants, and further enhanced by biological activity (particularly micro-faunal) in the immediate area. Both biological and physical transport mechanisms then serve to increase concentration of limiting resources in these fertile islands; they gather nutrients from surrounding areas, and retain resources already present. Soil micro-flora and fauna around tussocks may help mediate these processes by converting materials and re-locating them through the soil profile. It is probable that tussock grasses alter nutrient levels (particularly nitrogen), soil moisture regimes, and solar radiation input, thereby ameliorating local conditions and serving as recruitment foci for herbaceous species in managed ecosystems in Queensland.

Degradation of natural landscapes with long-term excessive grazing causes loss of basal area of tussock grasses, and litter cover, as bare interspace increases. Soil characteristics (soil pH, bulk density, water holding capacity) important in water movement and nutrient levels, are adversely effected. Microbial communities, which are important in mineralisation of key nutrients, rely on carbon found in litter and dead roots to supply carbon for growth and reproduction. Increases in bare interspace may limit availability of nutrients in these zones, and help hamper landscape recovery.

Objectives: The aim of this study is to quantify the micro and meso-scale spatial distribution of various soil resources in tropical grasslands in different stages of desertification. Data collected in this study will allow a test of whether tussocks of perennial grasses in Queensland actively "capture" resources in runoff from inter-patch areas that could affect biogeochemical cycles, or affect future community structure at the micro-topographic scale. Areas of specific interest will include: 1) seed-bank dynamics; 2) dynamics in the microbial population; and 3) nutrient load around tussocks of different grass species and related bare inter-patch zones. Description of changes in distribution of soil properties may provide an index of the states in desertification of grasslands in Queensland.

Methods: Materials to be analysed will be collected from experimental paddocks exhibiting different pasture transitional states and with different levels of utilization, within the Cardigan site near Charters Towers. State classes included represent different stages in the desertification of landscapes. Areas sampled will include tussocks of *Heteropogon contortus, Chrysopogon fallax, Bothriochloa ewortiana* and bare patches to serve as a control.

Plant properties measured will include basal diameter and/or circumference of tussocks; above-ground biomass, with standing biomass and litter determined separately; biomass density (from standing biomass/basal diameter) and stem density (if time and manpower permits).

Soil samples will be collected at a fine scale of resolution laterally, with sampling oriented in an upslope-downslope direction. Vertically, soil will e collected from the 0-5 cm layer (the zone of maximum microbial activity and nutrient load), and from 5-10 cm. Little is known about microbial activity at this depth, though it is thought to be low. Characteristics to be measured include:

- Soil seed bank — total numbers of seeds and total number of seeds will be determined. Determination of numbers of species will also be completed. Viable seeds will be separated from samples.
- microbial biomass — microbial biomass will be determined with the fumigation-extraction method and the density and richness of microbial species will be determined (if resources are available).
- mineral nitrogen and phosphorus.

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Appendix 1

TERMS OF REFERENCE

1. To collate, review, critically evaluate and provide a concise report on the current state of information and knowledge on interactions between clearing, pasture improvement, grazing management, drought, vegetation cover, soil erosion and downstream effects on the hydrological cycle in northern Australia. The amount and quality of surface water, the capacity of groundwater and the ecological status of riverine systems are all important aspects of this work.

This review should include both published scientific literature and current and ongoing research, identify the sources of information and provide an indication of the extent of their program commitment to such research and development work.

2. To identify the key players, whether individuals, groups or institutions, involved in R&D in these areas.

3. To identify major issues and problems in this area for both economic production and ecological sustainability within the beef industry and for downstream systems.

4. To identify those aspects of current knowledge which might immediately be translated into strategies which can be adopted by beef producers or others in the community who are seeking to improve profitability, international competitiveness and ecological sustainability.

5. To identify critical gaps in knowledge or uptake, to indicate the significance of these gaps to current land and water management, to identify the end-users of new information which might be generated and to specify R&D activities which might overcome those deficiencies.

6. To make recommendations as to work which might appropriately be funded by Phase 3 of the MRC's North Australia Program, taking account of the need to improve adoption of ecologically sustainable resource management systems and their profitable utilisation.

7. To prepare a draft report and present it for review by a forum of northern Australian beef producers and others with responsibilities in natural resource management in northern Australia. This forum would be organised by the MRC, but would require significant preparation and appropriate presentation from the review team.

8. Following that consultative forum and discussions with the MRC's NAP3 program coordinators, to prepare a final report which includes a short summary suitable for publication by MRC and circulation throughout the northern Australian beef industry, R&D agencies and relevant scientists.

are regulated or unregulated. It is also recommended that this scoping project assess the land system and other resource mapping information available across northern Australia. Such assessment is necessary partly as land system information is considered a necessary basis for any large scale catchment work and would need to be obtained if not already available, and partly because it is also useful for property planning, particularly if the mapping is incorporated within a geomorphic province framework which identifies the broad susceptibility of different landscapes to degradation. The assessment needs to consider the scale of mapping and the land characteristics used to delineate mapping units. Note should also be made of catchments in which NAP3 projects arising from NAP2 projects, are being undertaken.

There was agreement that the selected catchment should be broadly representative across these criteria so that the work conducted in one or two locations would have some applicability elsewhere.

6.4.2.3. Recommended research

The third recommendation was to establish a project or projects to identify and measure the significant effects that the north Australian beef industry is having on the movement of water and nutrients within the catchment and the effect of this movement on water quality and the sustainable use of other resources.

It was recommended that the objectives of this work pick up a number of the recommendations made in Section 6.3., particularly the second recommendation in Section 6.3.3.1 and the third recommendation in Section 6.3.2.4. More specifically, it is recommended that the research involve:
- an analysis of the surface hydrology, landforms and patterns of sediment generation, transport and deposition, and the delineation of geomorphic provinces;
- an interpretation of the inherent capacity of these provinces to supply sediment and nutrients to the major river systems and the susceptibility of the land within them to degradational processes as a result of specific grazing practices;
- establishing budgets for water and key nutrients at paddock to catchment scales, using the provinces as a guide to major landscapes for which budgets are required;
- examining the extent to which grazing and grazing management practices enhance loss (as distinct from redistribution) of water, sediment, nutrient or organic matter, from local areas (ie, catchment divide to water course); and
- determining the effect any such losses are having on land functioning and productivity.

It was recognized that this project needs to be linked with the biodiversity research that will be funded in NAP3.

References

Christian, C.S. and Stewart, G.A. (1953). General Report on Survey of Katherine-Darwin Region, 1946. Land Research Series, No. 1. (CSIRO: Melbourne).

Smith, E.L. and Novelly, P.E. (1997). The assessment of resource capability in rangelands. Occasional Paper No 08/97. (Land and Water Resources Research and Development Corporation: Canberra).

Tongway, D.J. and Hindley, N. (1995). Manual for Soil Condition Assessment of Tropical Grasslands. (CSIRO Division of Wildlife and Ecology: Canberra).

- The importance of an integrated approach to catchment management was emphasised. It was considered appropriate to bring the many other R&D players into NAP3 catchment management research relating to the beef industry because the totality of effort needed in relation to catchment management, water quality and nutrients is much larger than can be supported under NAP3 - there is a strong need to bring together and integrate the expertise (and the funding), and to deliver the sort of integrated outputs that catchment communities and landholders seek.

- In the context of integrated catchment management, it is also necessary that any R&D undertaken is linked to a range of decision-making processes, for example to catchment management for land use planning, to industry practice and also to individual decision-making at the property level. It was emphasised that changes in land management practices at the property level would not be made unless the information from the research was useful to managers and put in an economic context.

- There is a need for the research to identify broad principles that can be linked with particular mapped land systems - this is one way of providing research outputs that can be extrapolated and adapted for use elsewhere. An issue of importance is the actual location of particular land uses and management practices within a catchment or landscape, this being equally or more important than the intensity or duration of use.

- There is a need to test and develop best-bet management practices as the industry and landholders cannot afford to wait until the final bit of research information is in - there was general agreement on the important concept of adaptive management, that is, applying the best-bets of today and monitoring their effectiveness so that they can be improved and adjusted over time.

6.4.2. Recommendations arising from the August workshop

As well as these general principles, three specific recommendations were made at the workshop. The first two were recommendations for more preliminary work to be undertaken before development of the final research proposal, and the third was a recommendation for the type of research to be undertaken.

6.4.2.1. Further information on current projects

It was recommended that current projects related to water and nutrient movement, and catchment management more generally, should be assessed to identify more specifically the knowledge that is being obtained and any deficiencies of the work. This will require the collection of further details on the problems being addressed, project objectives, methods being used, where the work is being undertaken, the organization that is doing it, the timescale and the sources of funding. NAP2 projects that are being extended into NAP3 need to be included.

6.4.2.2. Identification of appropriate catchment(s) for research

Given that research will need to be limited to one or two catchments, an important issue is the catchment(s) in which the research should done. It was agreed that a scoping study should be undertaken as a matter of priority and that it should consider all catchments across northern Australia. It was also agreed that the study would begin by establishing a number of criteria against which catchments would be ranked and grouped. Some of the suggested criteria are:

- a high potential for the grazing industry to affect land and water quality;
- a catchment community that wants the sort of information that will be generated by the research;
- a catchment that is considered to be important from the point of view of the grazing industry; and
- an effective extension process already in place to pick up research results and incorporate them into catchment planning.

The first criterion requires characterisation of catchments in terms of biophysical attributes, including geomorphology, climate and land use, in an attempt to identify potential vulnerability to degradation and risk of off-site effects. Also important are whether catchments are coastal or inland and whether rivers

Resource Science and relevant state agencies. The National Landcare Program has also been assessing survey coverage and this is another potential source of information.

- Without pre-empting the findings from collation of land resource information and use, it is suspected that there has been relatively little interpretation of land system/land unit data to provide assessments of the variability in inherent productivity and inherent susceptibility to deterioration within a landscape. Both are regarded as necessary inputs for property planning. Relatively rapid qualitative assessments can be derived from information obtained during land resource surveys. Methods for quantitative assessments also need to be developed and used where appropriate, and modelling is anticipated as being a useful method.

- Following assessment of the current status of land system survey work and State programs, it is recommended that priorities for improvement in current land system survey coverage need to be developed, and mapping and interpretations of resource productivity and susceptibility to degradation, undertaken. It is suggested that land system mapping should be undertaken in conjunction with the geomorphic province mapping (recommended in Section 6.3.3.). Geomorphic provinces identify the broad regional controls on landscape processes and stability, imparted by geomorphological processes. It therefore provides a useful framework for broad qualitative assessments of inherent stability/instability of the land systems grouped within them. The province framework provides a means of understanding the inherent stability, resilience and susceptibility to degradation of individual land systems/land units determined by the climatic, topographic, soil and vegetation characteristics of each.

- An important issue not investigated in this review, is the appropriateness of research techniques and models which use digital elevation models (DEMs) for providing quantitative assessments of resource productivity and susceptibility to degradation. Presumably, for example, there are the threshold values for relief (slopes) which must be exceeded if DEMs are to be useful. Similarly, there are likely to be slope values at which distribution of the vegetation and soils tend to exert greater control on surface flow than topography. It is recommended that this issue is investigated, given that DEMs and models based on them are being widely promoted as useful tools for improved resource assessment.

6.4. Guiding principles for a research program and recommended research priorities

At the workshop held in Brisbane on August 7th, 1997, the above recommendations for research were extensively discussed. A number of principles emerged and priorities for research program developed. These are outlined below.

6.4.1. Guiding principles

- The vision and design of land use takes place at a regional or catchment scale, while the changes in improved management take place at the paddock or property scale. It was felt that new work in the NAP3 program needs to be primarily at the large catchment scale. It was also considered that the problems associated with linking sediment and nutrient transport processes at different scales were more important issues than water quality per se.

- There are major biophysical and industry differences between catchments across northern Australia which makes funding research, particularly at large catchment scale, a challenge for the NAP3 Program with its limited resources. Another difficulty is the relative lack of expertise in northern Australia (in relation to size) and the concentration of research staff in a few localities. An appropriate solution is to support research, which can provide principles for adaptation and use in other northern Australian catchments, at perhaps one or two locations.

conditions that inhibit bloom development could be important in elucidating mechanisms of bloom formation in those areas where cyanobacteria are a problem.

- Relatively little is known about the grazing pressures that are exerted on riparian areas in different land systems and how these vary seasonally and during periods of drought; the degree of utilization that is compatible with maintaining the natural habitat and biotic communities; and the effect of cattle exclosure. Improved knowledge of these aspects will help in managing riparian zones.

- The possible introduction of weed species to new areas with the further development of ponded pastures, is regarded as a particularly important issue given the very great difficulty associated with eradicating weeds once they are established and the enormous costs involved. While the benefits of ponded pastures are acknowledged, it would seem that the potential exists for these to be outweighed by the long term costs. If further development of ponded pastures is planned, an improved understanding of the costs and long term benefits is highly desirable. Determining environmental cost will, in turn, require improved understanding of the potential of several of the aquatic pasture species to become environmental weeds.

- Continued survey/documentation of terrestrial, estuarine and marine biota and their condition, and research into ecological and physical processes, is necessary to ensure that we understand these systems, the conditions they can tolerate and when undesirable changes are occurring.

6.3.5. Land survey and assessment of land resource capability

Generally pasture type seems to have been the basis for most research planning and resource capability assessments in the rangelands but the recommendation made in *The Assessment of Resource Capability in the Rangelands* (Smith and Novelly 1997), that resource capability assessments should be based on land system/land types, is adopted here. Climate, geology, topography, and soils are all important in determining land productivity and its susceptibility to degradation, and hence need to be considered in resource assessments.

Land system survey, in which land is classified according to variation in climate, geology, geomorphology, soils and vegetation, has a long tradition in northern Australia, the technique having been developed there with the initial survey of Christian and Stewart (1953). Large areas of northern Australia have since been covered by land system mapping but the use made of this appears to be variable, as is the information contained within the surveys and their scale of mapping.

Land system surveys are useful both as an inventory of resources, and as a basis for assessing land productivity and susceptibility to degradation. Similar land types tend to have similar processes and hence land systems also provide a useful basis for the extrapolation of research. Grazing management practices need to take account of the variation in land resources, the processes operating, and the productive potential of the land as well as its susceptibility to degradation. Consequently, land system and component land unit mapping are also regarded as providing essential information for property planning.

6.3.5.1. Recommendations

- As part of this project, it had been intended to review land system and other land resource mapping information (eg, the soil fertility mapping in central and NE Queensland, major flora and fauna surveys) available for Queensland, the Northern Territory and NW Western Australia and the resource assessment procedures in use. Some data were collected (see Chapter 5), but no systematic assessment of their scale and content was made. It is therefore recommended that a short project be undertaken to assess the current status of land system and other resource survey work across northern Australia, the information contained in the reports, and the land capability assessments (including carrying capacity estimates) relevant to rangelands that are being derived from them. It is expected that much of the information would already be collated by the Bureau of classes? There is also little understanding of the capacity of different landscapes to produce and transport sediments.

Research in this area is regarded as fundamental. Until we have a greater understanding of the dynamics of sediment generation within, transmission through and output from, large catchments, the time-frames involved and the effects of grazing on these processes within different parts of the catchment, we will still effectively be guessing as to the effects that grazing is having on outputs of sediment and nutrients to coastal environments. Knowledge of these processes and their variation within a catchment is critical to developing management strategies that deal with sediment and nutrient problems downstream adequately and realistically. Without it, management strategies may be misdirected and relatively ineffective.

6.3.3.1. Recommendations

There has been so little work studying the functioning of large catchments that there are probably many areas of appropriate research and investigation. Several appropriate areas are suggested below.

- Investigation of sediment rates in estuarine/marine environments and the effects of terrestrial inputs on coral growth are both potentially techniques for determining how terrestrial inputs to the marine environment have changed over time, including in response to natural shifts in climate prior to European settlement. This knowledge would provide a context for the current input of sediment and indicate whether current rates are significantly larger than those which have occurred previously under natural conditions. Such an understanding is necessary to assess whether, and if so, to what extent, anthropogenic activities are causing the system to function outside its normal limits, and hence the management changes needed in order to return to land fluxes that are within the limits of those known to occur naturally.

- Analysis of the surface hydrology of landforms and patterns of sediment generation, transport and deposition, suggest that not all parts of a catchment are equally important in generating sediment that is exported from a catchment. Delineation of "geomorphic provinces" (see Review 4 for an explanation) on the basis of the predominant erosional/depositional regime resulting from the influence of geomorphic features (usually relative rates of opposing processes, the presence of local base-level or the presence of a specific substrate, such as weakly consolidated material) is suggested, particularly if experimental (such as sediment tracing) and water monitoring programs are to be undertaken. It would seem appropriate to develop hypotheses of sediment generation which experimentation and monitoring can help validate, rather than to hope that experimental work and monitoring will automatically elucidate important processes and landscape differences.

- Experimental work, such as sediment tracing, could be undertaken to help determine both the landscape regions within a catchment that are primary sources of sediment, as well as whether the sediment is derived from sheet or gully erosion, or floodplain scour. Different size classes of sediment would need to be considered.

6.3.4. Effects of grazing and grazing management on riparian, aquatic and marine biota

Issues that are considered particularly important in the effect that grazing and grazing management are having on the biota of different aquatic environments are listed below.

- With respect to blue-green algal blooms, the lack of bloom development in the NT and north-west of Western Australia is important. The question is whether changes in management, for example an increase in stock numbers, could lead to bloom development or whether there are environmental conditions peculiar to these areas that are inhibiting bloom formation. Either way, there are implications for management. In the first case, the implications are for the grazing enterprises in the NT and north-west of Western Australia while in the second case, knowledge of environmental

- Water balances at paddock and small catchment scales and their variation over time are unknown for many climatic regions and major land types, as is the effect on them of grazing and grazing management practices (control burning, tree clearing). A strategy needs to be developed for determining priority areas for undertaking hydrological monitoring/modelling work, with research projects implemented in these areas.

- Research is needed to determine the extent to which grazing is causing water, sediment, nutrient and organic matter to be transported out of, and consequently lost from, local areas and the effect that such losses are having on the functioning/productivity of land—vegetation—grazing systems. Consideration also needs to be given to the effects of drought and fire. This type of knowledge is needed for different land types.

- Greater understanding is needed at paddock scale of animal behaviour, and the factors influencing cattle preference for specific land and forage types, including their observed preference for bare and eroded land, locally known as "cattle camps". Use of riparian areas by stock and the sensitivity of these areas to grazing, is an area that particularly requires investigation.

6.3.3. Movement of sediments and nutrients within large catchments/river basins

Measurements of sediment and nutrient movement from plots and small catchments have been used to estimate the contribution of various land uses to sediment and nutrient (N and P) inputs to the Great Barrier Reef lagoon. Estimates of the contribution of grazing land range from around 66%-84%, with the percentage being much higher in individual catchments such as the Fitzroy and Burdekin. Given that grazing enterprises occupy around 87% and 95% of the area of these two catchments respectively, it is hardly surprising that land used for grazing is regarded as a major contributor of sediment. If estimates of the contribution of different land uses to catchment sediment yield are ultimately derived from the area of the catchment with that land use, then the proportion of the catchment with a particular use will influence the importance of the land use in contributing sediment. In other words, in catchments such as the Fitzroy and Burdekin, one would expect a high proportion of the sediment yield to be derived from land covering 87% or 95% of the catchment, whatever the land use.

There are two issues here. One is the extent to which such methods of estimating contributions of different land uses to whole catchment sediment and nutrient fluxes are reasonable. The other is the extent to which grazing has *increased* fluxes within, and at the outlet of, catchments. It is the increase in flux that is important, firstly, because it is this increase that represents the effects of grazing, and secondly because it is not possible to reduce fluxes of sediments and nutrients to levels below those which occurred naturally.

Estimated contributions of different land uses to catchment sediment and nutrient export that are derived from plot studies take no account of material subsequently deposited lower on the slope or within the channel system. On the other hand, where estimates are derived from small catchment measurements, the source of material could be predominantly stream channels rather than slopes. Neither type of measurement (plot or small catchment) accounts for material subsequently deposited further down the channel network or on floodplains, although standard sediment delivery ratios have been used to try and allow for this. These methods also do not take into account sediment derived from channels further downstream and there are no data indicating whether this is an important sediment source. Other problems with this approach, acknowledged by those undertaking the studies, are that the estimates of fluxes associated with different land uses are based on very limited data sets that do not encompass variation in grazing pressures, land types or rainfall regime, all of which would be expected to have considerable effect.

Clearly, for river basins, we have very little knowledge of the generation, transport and output of sediments, the time-frames involved, the effects of grazing and the variability in processes depending on the sediment size-class. For example, are sediments derived predominantly from sheet, gully, stream channel or floodplain erosion and do the principle erosional processes vary for different sediment size-

Recently a number of projects have been initiated which are investigating inter-relationships between nutrients, soil biota and vegetation states. Even so, further investigation of the following interactions are considered necessary to obtain a better understanding of important processes and critical thresholds beyond which undesirable changes in land condition will probably occur.

- Pasture species/cover — nutrients — soil biota: improved knowledge is needed of nutrient pools (within the whole profile and not just the top few centimetres), budgets and cycling, including litter production and the role of soil biota, for different pasture communities (including improved pastures), and for different vegetation states within these communities.
- Soil properties (including biota) — pasture condition — water: the interactions between, and relative importance of, soil properties and soil biota in water infiltration and runoff, ie the factors predisposing different soils to sealing and loss of macroporosity under grazing and on exposure to rainfall, and the processes involved, need to be better understood. Similarly, knowledge is needed on the soil properties that need to be restored to restore infiltration, how restoration can be achieved and the length of time such restoration takes.

The effect of grazing and grazing management practices on the above inter-relationships need to be understood over long time-periods and for different land types. Long term changes are particularly important as such changes are easily overlooked due the short-term perspective that is generally currently taken in funding research.

6.3.2.2. Water balances —large plot to small catchment scale

There are relatively few quantitative data on components of the water balance at plot to small catchment scale either under natural or disturbed conditions. Simulation modelling has been used to indicate the likely episodic nature of recharge in some environments and its increase with land clearing. Very few experimental studies have been carried out.

Most work has focused on changes in runoff associated with increased grazing pressure. While heavy grazing has been found to reduce infiltration and increase runoff at patch scale due to reduced soil macroporosity and microtopography, and to loss of litter and plant cover, very little is known about how much of this water is actually lost from the local landscape (the area between the local catchment divide and the stream channel). Water that is lost upslope, may infiltrate further down the slope. Similarly, there is not a very good understanding of the extent to which sediments and attached nutrients are redeposited within the local landscape rather than being transported out of it. There is also little, if any, knowledge of the effect of such nutrient and soil loss on productivity.

6.3.2.3. Foraging behaviour —plot to small catchment scale

The way cattle utilize different land types and pasture communities and species patches within them at paddock scale, is needed to determine actual grazing pressures on different land types, communities and species, and also animal productivity. Greater understanding of foraging and animal behaviour is necessary to develop management strategies that are productive but which do not degrade areas attractive to stock. This is particularly so in those environments in which cattle movement is determined more by vegetation and soil types than by the distribution of watering points. Foraging behaviour is also important in understanding the effect of cattle on riparian and wetland areas, and whether all such areas are particularly susceptible to degradation through excessive use. Any investigations of foraging behaviour needs to incorporate years of below average rainfall.

6.3.2.4. Recommendations

- Further research is needed into processes involved in the loss of infiltration capacity for various land types under different grazing pressures, and the soil and vegetation properties which result in the susceptibility or resilience of the land to loss of infiltration capacity.

6.3.1.5. Recommendations

- Education and awareness programs need to be continued to increase knowledge of farm resources (land types and their vegetation and soils), and awareness of degradational effects of overgrazing, including the short-term profitability at the expense of the land and long-term productivity. They need to counter current faulty perceptions of land resilience and capacity to “come back”.

- There is a need for monitoring programs, the objective of which is to help improve grazier decision making with respect to property management. These programs probably need to be distinct from monitoring that has state or national planning and management objectives. There appear to be several programs or schemes already in place. Before recommendations can be made with respect to appropriate monitoring programs, there needs to be more information on their objectives, scientific basis and the actual information needed by managers.

- Developing economically viable and ecologically sound management strategies at paddock and property scales - can it be done? There appear to be numerous recommendations for improved management arising from research trials, most of which are being incorporated into various extension programs. A question that arises is whether we know how to integrate the various recommendations. For example, recommendations for use of fire to control woody weeds or manage pasture, may not be appropriate for maintaining biological diversity. Another question is whether practices which maintain the resource base can be combined with marketing and herd replacement strategies that are economically viable in both the short and longer terms. There is a need for putting together and demonstrating property and resource management strategies that integrate recommendations from various research areas, coupled with demonstrating that such management can be economically viable as well as ecologically sound.

  This is not a simple research area in that no organization has the expertise or facilities to undertake all the necessary work. A combination of approaches involving some research trials, case study analyses and co-operative research/on-farm projects will probably be necessary. Economic and resource evaluations are obviously major components of such work.

6.3.2. Land processes and the effect of grazing at patch, paddock and small catchment scales

Issues discussed here are primarily those relating to water, sediment and nutrients as these were the focus of the review; weeds and biological diversity are other aspects that have not been dealt with in this review though it is recognized that research associated with these areas needs to be integrated.

6.3.2.1. Patch scale

There are major gaps in our understanding of the interactions between the various components of the grazing system (see chapter 4 for details of components), and their variation with different land types and in time and space within a given land unit. Past work seems to have focussed predominantly on pasture—animal interactions, particularly the effect pasture composition and biomass have on animal production although more recently the effect of grazing on vegetation state has been considered in some detail. Greater emphasis needs to be given:

- to other system components and their interactions as the processes involved are critical to the proper functioning of the grazing system and must be understood if we are to manage the system effectively as well as repair systems which are degraded;
- to understanding the effects of different management strategies — these effects need to be understood both in terms of animal production and performance, as well as in terms of effects on the land resources and their functioning; and
- to integrating the different component processes to give a fuller understanding of how the grazing system is functioning.

6.3.1.2. Specific management practices

The assessment of this review is that there are few specific management practices that can be prescribed uniformly for the entire north Australian grazing industry. For example, maintaining a pasture cover of 40% has been found to be a useful guide to cover levels to prevent very high runoff, sediment and nutrient losses in more humid areas, but it is inappropriate in arid regions. Similarly fire is regarded as a useful management tool for maintaining some species but its use is not universally supported. There appears to be concern, for example, over its role in the loss of perennial grasses from some pastures in the north where perennial plants will grow in pastures now dominated by annuals if fire is excluded (David Tongway, pers. comm).

Rather than identify and promote prescriptive management practices, it seems more appropriate for this review and NAP3 to define and promote principles. For example, such a principle may be that grazing should be managed so as to retain sufficient plant cover and patchiness to ensure that materials are only transferred locally (on a slope) and not out of the system, or that soil biomass and carbon are not reduced below particular critical levels. Indicators are needed of land-soil-vegetation interactions and of key processes for different land types so managers can make sure stocking rates comply with these principles. The trigger-transfer-pulse framework (developed by CSIRO Division of Wildlife and Ecology) and the indicators of soil condition based on this framework (Tongway and Hindley 1995) are being found to be relatively robust for identifying the functional behaviour of the land over a range land types.

6.3.1.3. Grazier knowledge of land resources

The knowledge of graziers of pasture species and their awareness of differences in land type seems to be variable, though it is generally agreed that ecosystem processes are not well understood. Some graziers know their land and grasses even if they do not know the technical terms, while it seems that other graziers do not have the same knowledge of their property resources. It is not possible for graziers to adjust management to suit differences in land and pasture productivity and susceptibility to degradation if they cannot recognize their land and pasture types. There still appears to be a need for increased knowledge of land resources and ecosystem processes if land management is to be improved. The guides to pasture plants and native species that have been produced over the last few years should go a long way in helping to achieve this goal.

6.3.1.4. Property planning and protection of sensitive areas

Management that occurs purely in response to particular events, without clearly defined objectives and strategies, is unlikely to maximize profitability or protect the land. Stock management needs to be planned, taking into account the biophysical resources of the property and the way these are utilized by cattle, as well as climatic forecasts based on the Southern Oscillation Index (SOI), and profitable marketing strategies. Improving property management is a separate subprogram of NAP3 but it is important that this subprogram includes improvement in the knowledge and planned use of land types (including pasture); that is, that improved property management includes improved resource management through improved knowledge and planning of resource use.

Options for managing resource use in the rangelands are not great and have traditionally involved stocking numbers, location of watering points and the use of fire. While fencing is not a major management tool because of the extensive nature of grazing operations, increased consideration will need to be given to fencing off areas highly susceptible to degradation because of soil properties and/or because of the degree of selective utilization by cattle. Riparian areas, for example, are usually heavily utilized and loss of vegetation and soil degradation in these areas is likely to be particularly important in terms of sediment and nutrient transport to waterways. Protecting areas of particular significance for native flora and fauna from heavy grazing also has been recognized as an objective that will need to be incorporated in management plans if the natural biological diversity of the rangelands is to be preserved.

Measurement and treatment of phosphorus and carbon subsoil movement

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Objectives:

- To quantify the proportion of P and dissolved organic carbon (DOC) moving from soils into streams and water storages by subsurface flow at the hillslope scale.
- To characterise the chemistry, physical and mineralogical properties of the mobile P and DOC.
- To determine the extent to which lime and gypsum reduce the amount of P and DOC translocated through soils and the cost-benefit ratio of their application.
- To transfer results to Land Care officers and water and land management agencies through meetings, field days and the publication of a brochure.

Fitzroy catchment, Queensland

Effects of episodic events on aquatic ecology in tropical and subtropical areas (project still at scoping stage)

Objectives: The project aims to test the hypothesis that algal blooms are part of an aquatic ecosystem response to variations in flow and nutrient loadings and to variations in the cycling of major nutrients within river sections and storages. In particular, the experimental design has been developed to test the hypothesis that gross changes in the biogeochemistry of C, N and P (particularly denitrification) after high flow events are coupled with the dominance of N fixing cyanobacterial blooms.

Proposed methods: The project will study in detail the effects of variations in flow (both high and low flow periods) on the ecology and biogeochemistry of river sections and barrages. An attempt will be made to obtain mass balances for nutrients, algal biomass and species composition in selected river sections which experience large variations in flow on an annual basis. It is suggested that this should be done by selecting a small number (3-5) river reaches in a well gauged catchment and sampling at gauging stations at the upstream end and downstream ends of river reaches and barrages. This will provide inputs and outputs of water, major elements, turbidity, salt and plankton populations for each section. Integrated samples of in-stream concentrations of nutrients are required from stations in the middle of each reach. Phytoplankton biomass and species composition should be measured on all samples. Macrophyte abundance in each reach should be assessed and sediment/water exchanges determined at a range of sites (3-5) in each reach.

Expected outcomes: Expected outcomes include an indication of whether nitrogen plays a role in the growth of cyanobacteria in rivers and storages and about the role of denitrification. The results are not expected to be catchment specific but transportable to other catchments and situations. The results are also expected to have clear management implications in terms of relationships between land use, nutrient loads and algal blooms.

2. Nutrient availability:

   To determine the role of the relative supply of nitrogen, phosphate and silicate (N:P:Si ratios) and rate of supply on phytoplankton species succession using: *G. catenatum*, *Prorocentrum spp.*, *Scrippsiella sp.*, *N. spumigena*, *A. circinalis*, and *Skeletonema costatum.*

   - Interaction of water column stability/turbulence with nutrient gradients (species for objective 3 as listed in objective 2).
   - To establish the relative importance of light attenuation and sedimentation on succession, particularly with respect to development of cyanobacterial blooms.
   - To determine the role of water column stratification due to salinity and temperature on the competitive ability of bloom-forming dinoflagellates and cyanobacteria relative to other phytoplankton groups, both with evenly distributed nutrients and vertical nutrient gradients.
   - To determine the role of variation in the frequency and severity of physical disturbances (simulated turbulence, natural and man-made) on the viability and competitive ability of dinoflagellates and cyanobacteria to initiate and develop blooms.

Retrospective study of nutrient variations in some riverine systems

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Objectives:

- Review of literature on stable carbon and nitrogen isotopes in freshwaters, and assess its applicability to interpretation of data from the Murray-Darling Basin and southern WA.
- Analyse C & N isotopes and P/Fe ratios for sediment cores from Lake Alexandrina, Namoi River, Burrinjuck Reservoir, Goulburn-Broken River, Fitzroy River and Wilson inlet (WA).
- Assess the significance of temporal changes in sources and relative fluxes of organic C, N, P inferred from sediment core data, to that of water column and trophic state over the past several hundred years.

Methods:

Sediments will be analysed by continuous flow mass spectrometry. Chronological information will be provided by ^{137}Cs and/or pollen dating. Also, use of existing archival data on algal abundance and nutrient concentrations from the respective catchments.

Movement of phosphorus through soils

Dr Jim Cox,
CRC for Soil & Land Management,
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GLEN OSMOND, SA

Objectives:

- To quantify the extent of P movement through a range of soil types.
- To establish the climatic factors (eg storm intensity, seasonal wetting and drying) which influence P movement.
- To quantify the effect of soil properties (eg sodicity, porosity, texture) influencing P movement through soils.
- To devise a P movement index (PMI) to predict the extent of P movement through soil types based on readily measured soil properties.
- To determine the extent to which lime and gypsum reduce the amount of phosphate translocated through the soil profile.

ATTACHMENT 1 — RESEARCH WITHIN THE NATIONAL EUTROPHICATION MANAGEMENT PROGRAM

Generic projects

Modelling nutrient release from sediments and lowland rivers and storages

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Monash University,
CLAYTON, VIC

Dr Phillip Ford,
CSIRO Land & Water,
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Objectives:
- Develop a conceptual model of the key microbial and chemical processes involved in nutrient diagenesis in sediments, incorporating the availability (and quality of) organic carbon and of electron acceptor species (ie, 0_2, $N0_3$, Fe (III), SO_4).
- Couple the microbially mediated sediment diagenesis model with a realistic quantitative physical transport model and implement the numerical solution of the resulting coupled partial differential equations.
- From a critical review of the literature, collect values for all parameters required to operate the model under conditions appropriate to Australian waters. Identify cases where adequate parameterization for specific chemical or microbiological processes is not to hand.
- Determine the missing parameters through judicious laboratory experiments.
- Using the model calculate profiles (and flux rates) of N and P species under conditions representative of episodic oxygenation typical of seiching, wind set up, operation of destratification systems, and intermittent flows.
- Apply model to calculate fluxes and nutrient concentrations in specific rivers in NEMP focus catchments.
- Document model.
- Disseminate results and transfer technology as appropriate to river managers and other key target audiences.

The interaction of physics, biology and nutrient regimes on the initiation and development of algal blooms

Dr Susan Blackburn and Dr Peter Thompson,
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Objectives:
1. Regulation of resting cyst germination:
    - To determine the role of the key environmental factors, light, temperature, salinity, dissolved oxygen and nutrient concentration on resting cyst germination of the bloom-forming dinoflagellate and cyanobacterial species: *Gymnodinium catenatum* (and *G. impudicum* if verified from Wilson Inlet), *Nodularia spumigena*, and *Anabaena circinalis*.
    - To establish endogenous dormancy requirements of resting stages of bloom-forming dinoflagellate and cyanobacterial species (as listed above).

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8. Recommendations

1. In Queensland the cattle industry should aim to decrease sediment (and nutrient) loads to waterways as a long-term process of improving downstream water quality.

2. In Queensland, given the potential for toxic cyanobacterial blooms, the quality of water used in intensive animal industries or wherever stock drink frequently from the same waterbody, should be monitored to prevent toxin accumulation in animals.

3. There is no evidence of the cattle industry in the NT and northern WA causing, or exacerbating, cyanobacterial bloom formation. However, there may be a number of factors involved in preserving the good water quality in these two states and therefore management changes which increase cattle numbers and access to streams, or sediment and nutrient inputs, should not be allowed.

4. Research is needed to understand why cyanobacterial blooms may be uncommon the NT and northern WA, but common in most parts of the other states of Australia, including southern WA and Queensland. The answer may influence how cattle are managed in these two states and lead to a greater understanding of why blooms occur so easily in other parts of Australia.

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experiences relatively high sediment deposition. Lake Argyle and its catchment experiences a strongly seasonal tropical climate with a hot summer wet season and a long warm to hot dry season. However, while there are state agencies which monitor a number of water quality parameters (although no parameters for productivity) officers report no observations of blooms. After a recent visit to this lake, Gary Jones concluded that this waterbody was apparently free of algal bloom problems. While Lake Argyle appears to be continuously of low trophic status, Jones suggested that this system needs further investigation to determine the processes controlling such low water column nutrient levels.

6. Animal Health and Algal Toxins

In a chapter of the report to the Prime Minister's Science and Engineering Council (Cooper *et al.*, 1996), Dr Gary Jones discusses the effect of algal toxins on the beef industry. Although this contains only a summary investigation, it indicated the potential for toxin accumulation in stock wherever stock drink frequently from water with an algal bloom problem. A pilot study has now been carried out by staff from CSIRO Land and Water and the Division of Tropical Agriculture and will be reported on later in 1997 (for details of this report contact either Dr Bob Hunter or Dr Gary Jones).

It is important to keep in mind that while pre-European Australia was susceptible to bloom problems, the recent proliferation of standing waterbodies has lead to a marked increase in the frequency of toxic cyanobacteria blooms. This was apparent in the major drought between 1991 to 1995 during which the wide-spread occurrence of toxic cyanobacterial blooms caused enormous problems to the Australian water industry. Increased algal blooms, coupled with the finding of toxins unique to Australia and with unknown properties, has the potential to affect the beef industry.

7. Summary

This review indicates that many of the standing water systems throughout Queensland are susceptible to cyanobacterial blooms. Blooms in pristine catchments indicate that the tendency towards cyanobacterial blooms is natural. However, there is also good evidence that nutrient loads to waterbodies will increase with increasing disturbance to catchments, and that the increased nutrient loads can contribute to a greater frequency of blooms and significant increases in the algal biomass. It would appear that there are two main processes causing eutrophication and cyanobacterial bloom problems in Queensland's waterbodies; (1) the relatively large nutrient loads carried by storm inflow events, and (2) P-release from anoxic bottom sediments following sustained hot/still dry periods. With respect to the cattle industry and downstream water quality, there is a need to reduce sediment loads reaching waterways. Where toxic algal blooms are common in water used for stock, the potential for algal toxins to accumulate in animals must be considered. Finally, while this does not apply generally to the cattle industry, it is also suggested that the use of sulfate-rich fertilisers in catchments be used with care to try and maintain pre-European soluble sulfate concentrations in Australian waterways and constrain the P-release process.

The data reviewed for the NT and northern WA indicates a similarity between these two states that contrasts with the situation in Queensland. Almost all the data reviewed indicate that waterbodies in these two states are generally in good health and of low trophic status. Management of cattle in these two states has to date had little effect in causing, or exacerbating, cyanobacterial bloom formation. For two large states, however, the amount of data available is very small, a result of algal blooms not being an issue. This was also the picture for Queensland pre 1992, with greater observation and monitoring indicating algal blooms to be a state-wide problem by 1997. It appears unlikely that this could also be the case for the NT and WA. There may be a number of factors which contribute to the generally low trophic status of waterbodies in these two states and, if this is so, then care is needed to not radically change the present status. This includes cattle stocking rates and cattle access to waterbodies.

1. Is this an isolated case or another example (like Queensland pre-1991) of a lack of monitoring and reporting water quality problems?
2. If this is an isolated case, and tropical NT does not have problem blooms at present, what are the factors causing this area to be different from other parts of Australia?
3. Is the present management of stock preventing significant influx of nutrients to waterbodies and preserving natural vegetation on the floodplain?
4. Is the hydrology of the region, relatively abundant riparian vegetation and generally good growth of macrophytes within waterbodies, controlling the nutrient status of the water column and preventing excess cyanobacterial growth?

It is important that at least some of these questions are addressed. Water quality may well be buffered by the climatic regime in this region, but there is always the possibility that there are other major factors. At present, NT waterways are free from algal blooms, but without knowledge as to why, it is possible that some anthropogenic change could create the water quality problems now found in Queensland.

5.3. Cyanobacterial blooms in northern Western Australia

As in the Northern Territory, there is very little water quality information available for the northern part of Western Australia. The W.A. Department of Agriculture and Waterways Commission considers that only the southern part of their state has algal bloom problems in either freshwater or marine environments. The following discussion is based on the observations of those who have worked in the area and a few relevant published water quality papers.

The region used by the cattle industry covers most of the top part of the state with a lower boundary which is the northern edge of the Canning Basin and the beginning of the Great Sandy Desert. The only other section of the state, above around the 25^{o} latitude, with a cattle industry is in the region of the Hamersley Ranges, again bounded to the east by the Great Sandy Desert. Observation by workers in the Kimberley region of WA suggests that this region has no algal bloom problems and the freshwater systems are dominantly good water quality; a point stressed by the state authorities contacted for discussions of this region.

There are two reports on the water quality of inland waters in the Pilbara region of WA (Masini, 1983; Masini and Walker, 1984) carried out for the WA EPA as part of a contribution to the State Conservation Strategy. These studies were carried out to examine the quality of water in this region, not because of problems with cyanobacterial blooms. These investigations of wetlands, creeks, springs and stratified waterbodies in the Pilbara region indicated, that of the waterbodies studied (12), all were generally healthy mixed communities. Only one waterbody was dominated by the blue-greens, but for all the systems examined chlorophyll a concentrations only ranged from 0.5 to 5.7 µg/L. The chlorophyll a values were similar to, or less, than those reported along the Harding River (the same region) by Dames and Moore (1975 and 1982) and are generally regarded as low values for freshwater systems.

As part of the Monitoring River Health Initiative in northern Western Australia, Stuart Halse (pers. comm.) comments that, in general, the waterways examined appear to be in good health and support good macrophyte growth. Water quality monitoring in the Gascoyne River, along the 25^{o} latitude, indicated data typical of other waterways in this region with low soluble P concentrations and therefore, low trophic status. Halse *et al.* (in press) have also examined Lake Gregory, a fairly large semi-permanent lake system to the east of the Canning Basin (i.e. just above 20^{o} 22' latitude). This generally freshwater lake system extends from arid into humid regions and has only dried twice in the last 25 years. Over several years of monitoring water quality in this lake, chlorophyll a concentrations have only ranged from 9 to <0.01 µg/L, suggesting a waterbody of low trophic status.

Lake Argyle is a very large, man made, lake situated only some 150 km (ca. 17^{o} latitude) south of Joseph Bonaparte Gulf (Timor Sea); the lake has a very large surface area relative to its water depth. The catchment of Lake Argyle is large (ca. 46,000 km^2) and relatively well stocked with cattle. A review of the effectiveness of an ongoing re-vegetation program in this catchment (Wasson *et al.*, 1994) indicated that the rates of sediment erosion have not been markedly reduced by the re-vegetation program and the lake still drying for relatively long periods with later flushing rains, could explain why these waterbodies generally remain free of excess phytoplankton growth.

Simon Townsend has observed that where cattle have access to natural waterbodies in the semi-arid tropics during the dry season, the waters can become extremely turbid. He suggests that while the dry season is the time of greatest potential for excess algal growth and P concentrations may be elevated (animal excretion and sediment disturbance), excess algal growth is most probably light limited. The water in 'turkey nests' (i.e. man-made dams) is generally clear and being relatively shallow many of these dams support good macrophyte growth; blue-green algal blooms are not known to be a problem in these dams. It is significant that in one case in central Australia where P and N were added to bore water to supplement cattle nutritional needs, the ponded water developed excess algal growth. The algae were not identified and the practice was discontinued. However, it does suggest that most water systems, at least in this region, are of low trophic status.

Water quality in two impounded waterbodies close to Darwin (the Darwin River and Copperfield Creek Dams) is also of interest in trying to understand the susceptibility of waterbodies in this part of Australia to cyanobacterial blooms. Simon Townsend noted that blooms of *Botryococcus bruani* (a Chlorophyte) occurred a few years after the impoundment of these two waterbodies, but cyanobacteria were not present in any significant numbers during these events. Townsend (1996) indicated that the Darwin River Reservoir normally has a low trophic status. Seasonal water quality measurements show that P concentrations have remained low (i.e. a bias towards high N:P ratios) even though stratification is strong and that there is a significant flux of Fe and nitrogen from the bottom sediments. Even when nutrient levels became high enough to support an algal bloom, N:P ratios still did not favour cyanobacteria. In contrast, water systems in Queensland are dominated by cyanobacterial blooms (Gary Jones, in press) and the algal biomass is generally N limited (i.e. high P:N ratios).

5.2.2. Billabongs

In the wet/dry tropics of the Northern Territory a general practice has been to allow cattle to graze floodplains during the dry season and move them to higher ground in the wet season. There appears to have been no clearing of floodplain vegetation (including riparian vegetation), but generally there are access paths to the billabongs. Normally cattle do not enter the water (steep banks or fear of crocodiles?) and do not defecate in the billabong. Cattle faeces accumulates on the floodplain over the dry season. In the wet season the floodplain billabongs on major water courses are flushed out, but some "back-flow" billabongs may be isolated from storm events.

The first flush of water entering billabongs can be high in nutrients, sediments and organic matter (Mary River floodplain billabong data, Townsend, pers. comm.) suggesting that this is when cattle grazing may have maximum effect on billabong water quality. Algal blooms, however, are unlikely to occur until the following dry season. One blue-green algal bloom has been recorded (Oct/Nov 1995) in a floodplain billabong with cattle access. The bloom was primarily *Anabaena* (90% by biomass) with a significant algal biomass (40 µg/L chlorophyll-a). The *Anabaena* featured heterocysts for nitrogen fixation and this suggests that the phytoplankton biomass was N limited. Simon Townsend states that the sediments in this billabong were mainly sand. If clay sediments were absent, then the absorption capacity of the bottom sediments to buffer inputs of soluble P from the cattle would have been low. The cause of the bloom however is unknown, but may have been due to either: (1) greater access and larger number of cattle entering the waterbody (i.e. nutrient enrichment due to excretion and/or sediment disturbance), or (2) the first flush of storm flow water from the previous wet, priming the system with nutrients, or (3) the result of land clearing and introduction of sediments containing P (i.e. *in situ* P-release from anoxic bottom sediments during the dry season).

The picture which emerges is that, at present, the potentially toxic cyanobacterial blooms, which are causing major water quality problems in large areas of Australia, are largely absent in the wet/dry tropics of the Northern Territory. This is surprising given that all standing waterbodies in tropical Queensland have the potential to develop cyanobacterial blooms. It seem, however, that in some circumstances cyanobacterial blooms can develop in billabongs. Although at this stage the 'key' factors causing these apparently isolated occurrences of cyanobacterial blooms are unknown, it does raise important research questions for future environmental management of waterbodies in the NT. Some of these questions are:

The processes leading to blooms in Queensland (Jones, in press; Harris and Baxter, 1996) are the same as found for much of Australia (see Background), but with probably a more pronounced climate-driven cycle (Harris and Baxter, 1996). Jones (1997) notes that the period between 1991 to 1995 (drought years) was a period where cyanobacterial blooms caused enormous wide-spread problems throughout Australia. Long hot dry years lead to prolonged periods of high surface water temperatures, stable stratification and P-release from anoxic bottom sediments, all of which favour cyanobacterial blooms. Another process noted in the study by Jones (1997), is the effect of the introduction of relatively large loads of nutrients into waterbodies during storm in-flow events. The large bioavailable nutrient load introduced with storm in-flow has been shown to sustain large algal populations, over time, even while a reservoir has undergone hypolimnetic oxygenation (Harris and Baxter, 1996).

The reports of cyanobacterial blooms in Queensland are usually for waterbodies in catchments associated with some land disturbance. Some reports however, come from pristine catchments indicating that bloom formation also occurs naturally. While algal blooms can occur naturally, it must be stressed that continuing catchment degradation will only exacerbate the problem through nutrient inputs in high storm flows. Additionally, to reduce the frequency of algal blooms, some attempt must be made to stop the *in situ* cycling of nutrients from anoxic bottom sediments. In this regard it is suggested that, in catchments with both grazing and agricultural activities, improvement in downstream water quality will come both from decreasing the storm-driven nutrient loads and from decreasing the concentration of sulfate in waterways, derived from fertilizer, to pre-European levels (i.e. <10 mg/L).

Rayment and Neil (1997) noted that cattle are now well distributed over the extensive grazing lands of Queensland. In catchments draining to the Great Barrier Reef, extensive grazing accounts for >85% of total land use, while fertiliser use is dominated by the sugar industry. These authors also suggested that sediment yields were higher (up to four times) under current land use compared with what they would have been for naturally (Rayment and Neil, 1997; see also Hunter *et al.*, 1996). Certainly disturbance leading to loss of riparian vegetation can be a major factor in increasing sediment loads to rivers. As well, Bramley and Johnson (1996) noted in a study of the Herbert River catchment that, irrespective of the land use in the catchment (which included cattle grazing) that: (1) nutrients carried during flood events determined downstream water quality, and (2) nutrient losses, while greatest from the disturbed sub-catchments, were apparently not changed by the different land uses. The message is that all land users (including the cattle industry) should be aiming towards reducing erosion and nutrient loss as a result of their activities.

5.2. Cyanobacterial blooms in the Northern Territory

Water quality officers in the Department of Power and Water in Darwin, indicated that toxic cyanobacterial blooms were not considered a problem in the Northern Territory. As a result very few, if any, of the Department's water monitoring programs were aimed at monitoring the potential for any standing waterbody to develop cyanobacterial blooms and there are no published reports describing the occurrence or distribution of cyanobacteria. The following discussion comes mainly from observations, particularly those of Simon Townsend (Water Resources Division, Power and Water Authority, Darwin). Simon Townsend confirmed that information about the aquatic environment in the semi-arid and wet/dry tropics of the Northern Territory is extremely scant. Hydrographic and hydrological issues have dominated and only recently have issues relating to the aquatic environment been recognised.

5.2.1. Standing waterbodies

There are obviously not many natural standing waterbodies in the arid and semi-arid tropics of the Northern Territory and in general observations of these waterbodies indicate that cyanobacterial blooms are not a water quality issue. The deeper waterbodies occur in gorges and the energy of the wind through the gorges appears sufficient, most time, to provide efficient water column mixing. Most other (saline and non-saline) waterbodies are generally ephemeral and the systems can be efficiently flushed by the next rainfall event. Also, it has been observed in clay-rich areas, that the particle-bound P in waterways is less bioavailable in the wet season if sediments have been previously dried (Baldwin, pers. comm.). In these regions, natural which were presently experiencing problems with cyanobacterial blooms, and those areas in Australia with reasonable expectation of developing problem blooms. A number of points emerge from these data.

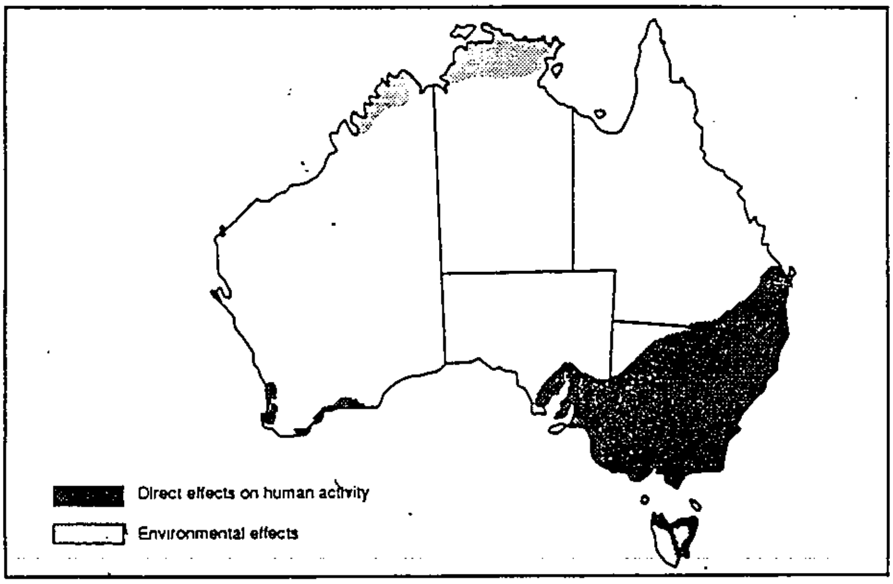

Figure 1. Areas with cyanobacterial blooms, reported by the Queensland water quality task force (1992)

According to this 1991-92 map, only a small part of southern Queensland had algal bloom problems, but within a year or so of this report it was known that almost all standing waterbodies in Queensland have algal bloom problems. Further monitoring and reporting has lead to a greater understanding of the extent of the problem and some understanding of the processes causing the blooms (e.g. Harris and Baxter 1996).

It is interesting that the 1991-92 map indicated an area in tropical Australia which would be susceptible to freshwater algal bloom problems due to environmental effects. The areas indicated covered, most of the top northern section of the NT and the top north-west section of WA. Given the present (1997) understanding the NT and WA water authorities that there are essentially no algal bloom problems in these areas, it would be interesting to know why these were considered potential problem areas in 1991-92. Their inclusion is even more unusual given that the 1991-92 report states that "to date, very few algal occurrences have been reported to the Water Resources Commission from tropical Queensland", and the tropic area of Queensland was not suggested as a potential trouble area. The report indicates that this figure was prepared by the Water Resource Management Committee of AWRC, an organisation that is now much reduced with no relevant staff from this period. Task Force members responsible for producing the QWQTF reports and who were contacted during this review, could not provide the answer as to why these tropical areas had been indicated as potential trouble spots.

5.1. Cyanobacterial blooms in Queensland

Dr Gary Jones suggests, on the basis of the reports he has received since being in Queensland (i.e. 1996 to the present), that nearly all standing waterbodies in this state are susceptible to cyanobacterial blooms. Volume 3 of the 1992 QWQTF report on algal bloom problems in Queensland, highlights Case Studies of 16 storages in Queensland having problems with algal blooms. Most of the identified storages (14) are in the bottom area of the state relatively near Brisbane; one was in the Rockhampton area and one was off the coast of Queensland (Palm Island) just north of Townsville. It is now known that weirs, farm dams and reservoirs throughout Queensland have had problem blooms (Gary Jones, pers. comm.). The area of problem blooms extends to waterbodies north of Cairns and to those in the west of the state, such as Lake Julius near Mount Isa (Jones, pers. comm.). It would appear that the only difference between this state and the known wide-spread occurrence of toxic algal blooms in NSW's water systems has been the identification, in tropical Queensland, of a new algal toxin apparently specific to this region (Jones, pers. comm.).

process are therefore: (1) to maintain sufficient flow in waterways susceptible to influxes of saline groundwater, and (2) decrease the use of sulfate-rich fertilisers so that sulfate concentrations in waterways are lowered back to pre-European values (i.e. <10 mg/L).

It is recognised that rangelands used by the pastoral industry for cattle would not normally receive significant amounts of fertiliser, although there is some use in areas of improved pasture. In areas of extensive grazing, the effect of grazing on increased sediment input and hence the *in situ* release of P, should also be considered in order to decrease the potential for eutrophication in these catchments.

4. Australian rangelands

The region considered in this report is north of around the 25^{o} latitude and dominated by summer rainfall. The environment of this large part of Australia ranges from arid to semi-arid tropics to the wet/dry tropics. Annual rainfall ranges from around 200-300 mm to over 1200 mm in the tropics. The strong seasonal monsoonal climate in the tropics produces virtual drought for up to 8 months of each year, but a relatively consistent hot summer wet season. Large areas of Australia, above 25^{o} latitude, are being used as rangelands for cattle; in the NT and WA in particular, much of this area has relatively infertile soils. Queensland has a relatively larger area of more fertile soils. It should be noted, however, that soils which are relatively infertile for pasture growth, can still provide adequate nutrients for excess algal growth due both to the lower nutrient requirements of algae and also to the *in situ* processes of P-release under anaerobic conditions in waterways. Phosphorus bound to clay and iron oxides is generally unavailable in soil but is released under anaerobic conditions in waterways.

There is good evidence that basaltic soils and the sediments derived from these soils can be a significant source of P for algal growth (Caitcheon *et al.*, 1995). In catchments with granite-derived soils (e.g. Murrumbidgee catchment), weirs and storages can also have cyanobacterial blooms. This is due to the preferential erosion and transport of very fine particle size (clays) from the mixed particle size soils developed on granites. This 'winnowing' effect can lead to a significant increase in the P concentration of river sediments over the original soil values.

Current evidence suggests, that unless sandy soils with very low clay contents dominate (e.g. the Peel-Harvey catchment in south-west WA), P will be mainly in the form of the clay/Fe/P association. Therefore, provided soils are not sands, standing waterbodies will be susceptible, during periods of hot/still conditions, to developing algal blooms. The greater the soil nutrient status, however, the greater the susceptibility. Queensland may be more susceptible to problem blooms because of the greater area of more fertile soils, a greater extent of fertiliser application and the creation of more standing waterbodies to cater for the larger population. Most standing waterbodies are however, related to farm supplies and irrigation.

5. Distribution of algal blooms across Australia

It is interesting that the first figure in Chapter 3 of the report to the Prime Minister's Science and Engineering Council, "Managing Australia's Inland Waters", shows waterbody monitoring sites covering most states; certainly a good distribution of sites in tropical Australia. However, while the authors of this chapter indicate the need for a further five years funding, the program covers only biological monitoring; the authors suggest this is a cost-effective way of monitoring river health. Unfortunately, the number of water monitoring sites across Australia measuring the data necessary to determine the extent of the algal bloom problem in this country is significantly more limited (Dr Gary Jones, National Algal Manager, pers. comm.).

The late 1991 algal bloom along the Darling-Barwon River brought attention to what was an existing problem. The much greater reporting of algal problems that was initiated, produced maps of problem areas covering most of NSW, large areas of Victoria and small parts of southern WA and SA. Later, water quality managers from Tasmania and then Queensland conceded that toxic blue-green blooms were common in many areas of their states. Identification of the problem had the effect of greater reporting and an emerging understanding of the aerial extent of the problem. However, this was a slow process as is illustrated in Volume 1 of the Queensland Water Quality Task Force (QWQTF, 1992) on freshwater algal blooms in that state (Figure 1). Maps in this report highlighted those regions of Australia, considered by the QWQTF, problem, and (2) the problem is widespread across southern Australia (including Tasmania) and extends into northern Queensland, but little information is available for either northern Western Australia or the Northern Territory.

Some of the processes important to algal bloom formation in Australia are listed below in point form. These provide the necessary background information for a discussion on whether the cattle industry in northern Australia is causing, or exacerbating, the problem of bloom formation.

1. Most Australian standing waterbodies (i.e. reservoirs, weirs, rivers during drought) suffer from excess phytoplankton growth and in most cases this is due to the potentially toxic blue-green algae. Toxins produced by these cyanobacteria could, under certain conditions, be harmful to the beef industry.

2. Studies on the source of the sediment reaching waterways in the Murray-Darling Basin indicate that subsoil rather than surface (possibly fertiliser-rich) soil dominates loads. Wasson *et al.*, (1996) comments that processes leading to subsoil dominated sediments may be a common feature of the Australian landscape.

3. The strong clay/Fe/P association in most Australian soils means that sediments from even relatively P-poor soils can produce a very large source of soluble P for excess algal growth in standing waterbodies.

4. Australian waterways are, in general not P-limited for excess algal growth, because of the long water residence times and the ease with which waterbodies stratify, producing deoxygenated bottom water.

5. Because of the strong clay/Fe/P association, point-source soluble P inputs to waterways (such as from intensive farm industries) may cause local algal bloom problems, but within short travel distances the P concentrations will be buffered by the major (diffuse) P load in the system.

6. The episodic nature of the Australian climate (i.e. storm events of days followed by long periods of drought) plays a major role in the eutrophication problems in our waterways.

7. Phorphorus reduction campaigns will only slowly lead to improved downstream water quality because of the *in situ* stores of P in most Australian waterbodies. To decrease the frequency of algal blooms in the short term, the major focus must be on the waterbody not the catchment. Present programs targeting waterbodies include flow management (environmental flows), destratification (hypolimnetic oxygenation), biomanipulation and sediment remediation to suppress the P-release process.

3. The P-release process

Fleischer (1978) found that a biochemical process regulated the release of P from anoxic sediments rather than the absence of oxygen. This finding supported earlier work by Hasler and Einsele (1948) that suggested that sulfate could affect the availability of P in bottom waters, because the sulfide produced by the sulfate-reducing bacteria disrupts the interconnections between the iron and P cycles.

Recently, Caraco *et al.* (1989 and 1991) used data from 23 different aquatic systems to indicate that the control of P-release from sediments by oxygen is not substantiated. Their data indicated that: (1) increased sulfate content of the waters was the major factor critical to the control of P release from sediments (through the activity of the sulfate-reducing bacteria); and (2) the difference between P-release under oxic and anoxic conditions maybe quite small, when sulfate concentrations are low. A recent study by Chiswell *et al.* (1995) confirmed the role of sulfate in P release from freshwater sediments, and a study of natural environments by Barbanti *et al.* (1995) confirmed the relationship between relatively large pore water P concentrations in anoxic bottom sediments and the activity of the sulfate-reducing bacteria.

Sulfate reaches Australian waterways by two main processes; (1) influx of sulfate-rich saline groundwater, and (2) the agricultural use of fertilisers (including superphosphate) containing calcium sulfate. There is now good evidence (from sediment cores and long-term water records) that the sulfate concentrations in waterways world-wide are increasing and that at these higher levels of concentration the sulfate is capable of promoting increases in the P-release process. Australian management options to decrease the P-release

1. Introduction

Hecky and Kilham (1988) have demonstrated that in inland waters phosphorus (P) is most likely to be the 'key' element limiting excess algal growth. Correlation models relating summer algal biomass production to the concentration of total P (Vollenweider, 1968; Dillon and Rigler, 1974 and Jones and Lee, 1986), at the start of the growing season, strongly support this 'key' element proposal.

In Australia in late 1991, the world's largest riverine cyanobacterial (blue-green algal) bloom occurred along 1000 km of the Darling-Barwon River. This event caused Federal and State Governments to react to what was actually a widespread problem. Water quality managers were then forced to carry out remedial programs where, particularly for inland Australia, knowledge of the processes driving bloom formation in this arid country was lacking. The adoption of northern hemisphere management practices to try and limit the frequency of bloom formation in Australian freshwater systems has lead to remedial programs which are either not applicable to this country or which will require decades, or longer, to produce improvement in downstream water quality (see e.g. Harris, 1995). Considering the large amounts of money being used for remedial programs, it is important that these programs are accurately targeted.

2. Background

Discussion of the sources of P in Australian aquatic environments has tended to accept as axiomatic that the predominant sources are the result of human activities. Certainly in the more heavily populated parts of the world, where the problems of eutrophication have been studied for decades (e.g. Europe and North America), there is considerable evidence for increases in P concentrations as having an anthropomorphic origin (e.g. Morse *et al.*, 1993).

There are few examples of direct human effect in Australian waterways (e.g. Birch, 1982; Hall, 1992) and it is becoming increasingly evident that the overseas experience is not directly relevant to the Australian environment. The processes/mechanisms are the same, but the balance and relative importance is not necessarily so, particularly because of the greater levels of turbidity in many of our freshwater systems. High levels of turbidity reduce light penetration and the strong particle-P association means less of the total P (TP) is immediately available for algal growth (e.g. Oliver *et al.*, 1993; Douglas, 1993). High TP concentrations can be tolerated in many of our waterways without causing excessive algal growth (Hart *et al.*, 1993).

Storm events deliver the major sediment and P loads to Australian waterways (e.g. Cullen *et al.*, 1978; Cosser, 1989; Gutteridge *et al.*, 1992; Olive *et al.*, 1994; Donnelly *et al.*, 1996). As gully density is often the parameter which best correlates with sediment loads to streams (Wasson, pers. comm.), subsoil rather than surface (fertiliser-rich) soil dominates these loads. Because of the strong particle-P association, point source contributions to clay-rich waterways may cause local problems, but this input is rapidly lost in relatively short distances downstream due to adsorption onto in-stream sediments (e.g. Jones *et al.*, 1993; House *et al.*, 1995). The degree of regolith weathering in Australia means that most Australian soils and sediments contain a large proportion of clay minerals and that there is a strong clay/Fe/P association (Norrish and Rosser, 1983; Donnelly *et al.*, 1997). This association means that during stratification, P-release from anoxic bottom sediments can be a very large source of soluble P for excess algal growth (e.g. Lawacz, 1985; Nurnberg *et al.*, 1987).

The high radiation levels in Australia, often coupled with turbid water systems, results in stratification of even relatively shallow waterbodies. The hot/dry climate results in almost all rivers being regulated to some degree and many water storages have been constructed to overcome water shortage during drought periods. Australia stores more water per capita than any other country in the world. The control of flow has resulted in the creation of many standing water bodies that undergo stratification and thus have the potential for resolubilisation of sediment-bound phosphorus. Harris (1995) noted the relatively long residence time for water in many Australian waterbodies and commented that in this country eutrophication is mainly the result of *in situ* P-release from anoxic bottom sediments.

Surveys of freshwater waterbodies experiencing algal bloom problems across Australia (Dr Gary Jones, National Algal Manager, pers. comm.) show that; (1) the potentially toxic cyanobacteria dominates this

Review 1

EUTROPHICATION AND ALGAL BLOOMS IN FRESHWATER SYSTEMS OF NORTHERN AUSTRALIA

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detrimental effects on stream fauna. Consequently the effects of grazing on riparian habitat discussed previously, can also affect aquatic biota.

5.3.1. Aquatic invertebrates

Invertebrates are an important component of the aquatic ecosystem and are a potentially valuable group to use as indicators of river health (Schofield and Davies 1996). Although information on the effects of grazing on aquatic invertebrates is currently poor, it is likely to improve with the publication of results from the Monitoring River Health Initiative. This national program coordinates the sampling of macroinvertebrates from hundreds of sites across Australia (including northern Australia) and will greatly expand existing knowledge of this group (Schofield and Davies 1996). In the NT, the Monitoring River Health Program has over 120 sites located across the Top End. Macroinvcertebrate samples and a range of physical and chemical measurements are taken at each site. Approximately 50% of these sites are subjected to a range of grazing pressures from cattle. Some of them show the effects of heavy cattle use with loss of vegetation ground cover, bank destabilisation, local catchment erosion and accumulation faeces (J. Suggitt, pers. comm.).

At present, there appears to be very little research in northern Australia specifically documenting the effects of grazing on invertebrate fauna in wetlands. Results of monitoring programs in the TFTA in Townsville revealed that while these streams have high macroinvertebrate biodiversity, reductions in diversity and abundance over time were correlated with increases in stream-bank degradation and turbidity due to grazing pressure (Pearson, 1996).

A recent study conducted in the Upper Brisbane River compared the chironomid fauna (midge larvae and pupae) and water quality of two sub-catchments with different levels of grazing (A. Arthington, pers. comm.). The more disturbed sub-catchment had five or six times higher electrical conductivity and concentrations of many inorganic ions, and twice the levels of suspended solids. The chironomid communities were also markedly different in the two catchments. Fewer species occurred in the more disturbed catchment, and it contained taxa usually associated with poor water quality. These taxa were absent from the less disturbed catchment. The faunal differences reflect the differences in the water quality of the two catchments and highlight the potential of these taxa to act as indicators of catchment disturbance.

Not all effects of grazing result in reductions of invertebrate richness or abundance. The presence of cattle hoofprints in the shallow wetlands of the Burdekin region increases available breeding sites for mosquitoes, especially *Aedes* spp. (Hearnden pers. comm. *cited in* Lucaks, 1995). However, this increase in mosquito abundance may not be desirable, particularly given the prevalence of arboviruses in northern Australia.

Literature from elsewhere in Australia has shown that many fish and invertebrates are susceptible to sedimentation, either through loss of interstitial habitat, suffocation (in gill breathing animals) or smothering of eggs. Given that several studies have described increased sediment inputs to wetlands as a result of grazing, it is likely that grazing induced sediment effects are widespread in northern Australia. This view is supported by a recent study conducted in Kakadu National Park, NT comparing two streams, one of which had undergone sedimentation in association with construction of a road crossing (Stowar *et al.* 1997.). The study found strong turbidity-related effects for macroinvertebrate communities inhabiting rootmat habitats. The communities from the sedimented sites were characterised by lower abundance of macroinvertebrates, particularly Chironomidae. Effects were not detected in sand habitats, probably due to the greater temporal and spatial variability in these communities.

5.3.2. Fish

The only direct evidence of grazing effects on fish relate to the decline of Red-finned Blue-eye (*Scaturiginichthys vermeilipinnis*) from the Edgbaston Spring complex in central Queensland. This species was described from six artesian springs in 1991. Since then it has disappeared from two springs and is now listed as endangered. The Action Plan for Freshwater Fishes (Wagner and Jackson 1993) identifies habitat destruction due to trampling, watering and grazing of cattle, and the excavation of the springs to increase water storage for stock watering, as factors that may have contributed to the decline of Red-finned Blue-eye.

There is also evidence that grazing may assist in the spread of cane toads (*Bufo marinus*). Cattle hoofprints can provide a favourable microclimate for toads, thus increasing their chances of survival during the dry season (R. Alford, pers. comm.). It has also been noted that borrow pits excavated for the construction of access roads for the pastoral industry has provided additional breeding sites for native frogs (M. Tyler, pers. comm.), although these sites may also assist the spread of the cane toad.

5. Wetland biodiversity

5.1. Aquatic macrophytes

Recent reviews of grazing in wetlands emphasise the lack of knowledge of grazing effects on wetland vegetation (Bunn *et al.* 1997; Finlayson *et al.* in press; Storrs and Finlayson 1997). Bunn *et al.* (1997) state that selective grazing of macrophytes, particularly in arid and northern Australia, is unchecked and that the repercussions for community dynamics and wetland succession are unknown. It has also been suggested that northern Australian wetlands may be more vulnerable to grazing than those in southern Australia, due to the massive concentrations of cattle around wetlands at the end of the dry season (Bunn *et al.* 1997). Furthermore, the highly seasonal nature of many wetlands in northern Australia means that cattle have greater access to a wetland as it dries out, exposing more of the wetland area to grazing and trampling disturbance.

A survey and classification of wetlands in the lower Burdekin region of north Queensland (Lukacs 1995) identified trampling and grazing and their subsequent effects as a current threat to vegetation of the Burdekin floodplain. Lukacs noted that the aquatic vegetation of the seasonal wetlands, particularly emergent plants, were especially prone to cattle damage as they were often grazed heavily during the dry season. Peripheral wetland vegetation is subjected to continual grazing pressure throughout the year.

Much research on the impacts of grazing on wetland vegetation in the NT has focused on the water buffalo. As these animals may use the land differently to cattle, their effects are summarised separately below. Effects of buffalo and cattle grazing on vegetation are being investigated in a long-term exclosure experiment on the floodplain of the Mary River, NT (D. Liddle, pers. comm.). This study is examining three different vegetation types with four replicates of grazed and ungrazed plots in each.

In a survey of the importance of black soil lakes of the Barkly and Sturt drainages as waterbird habitat, Jaensch *et al.* (1995) noted that lignum (*Muehlenbeckia cunninghammi)* and other plant species such as wild rice (Oryza spp) had declined or disappeared from parts of the wetlands where grazing had occurred. The disappearance of these plants from the Barkly wetlands is significant as Jaensch *et al.* (1995) found lignum to be the most important vegetation for waterbirds.

Other effects of pastoralism on native vegetation relate to the introduction of improved pasture species and are discussed below.

5.2. Algae

Current research on the Cooper Creek in western Queensland has revealed that food webs in these turbid river systems may be largely based on in-stream production of benthic blue-green algae (S. Bunn, pers. comm.). The high turbidity means that the algae can only grow in the shallow margins of the wetlands, making these systems highly susceptible to the effects of cattle trampling and to water drawdown.

5.3. In-stream fauna

Many aquatic vertebrates and invertebrates depend on riparian inputs (e.g. leaves, fruits etc.) for their survival. In addition to providing organic material which serves as habitat and food for aquatic fauna, riparian vegetation plays a crucial role in shading streams. Shading reduces both light and heat reaching the stream, which can lead to elevated plant growth and increases in water temperature – both of which may have relevant to this review as riparian zones appear to be important areas for granivorous (and nectarivorous) birds (Braithwaite 1985). Woinarski (1993) considers two other finches associated with riparian habitats — the Crimson finch and the Star finch — as species of conservation concern, again due to the potential effects of grazing in these habitats.

Observations of the link between the decline in riparian birds and drought and grazing, were first described by Barnard (1925) for the riparian grasslands in Queensland. However, the most well documented impacts of grazing have been on the Purple-crowned Fairy-wren and the White-browed Robin (Smith and Johnstone 1977; Boekel 1980; Rowley 1988; Woinarski 1992; Rowley 1993). These insectivorous species have disappeared from the riparian grasslands and fringing Pandanus from many areas in the Kimberley following the loss of this vegetation through overgrazing. The Western sub-species of the Purple-crowned Fairy-wren (*Malurus coronatus coronatus*) is now listed as vulnerable (Garnett 1992).

In a review of the conservation of birds in arid Australia, Reid and Fleming (1992) concluded that vegetation modification as a result of overgrazing had been the principal agent causing the decline of bird species within the arid zone, and that birds with a preference for grassy riparian environments and chenopod shrublands had been disproportionately affected.

4.2.3. Mammals

Morton (1990) constructed a conceptual model to account for the recent high extinction rates and dramatic range contractions of arid zone mammals. Although the model included several contributing factors, Morton (1990) argued that the primary cause for extinction of medium sized mammals from central Australia was habitat modification due to grazing by a range of introduced herbivores, including cattle. Medium-sized mammals were prone to decline because they were particularly dependent on moist and fertile patches in the landscape (including riparian habitats) during droughts. These habitats are also a natural foci for introduced herbivores and have experienced severe degradation through overgrazing (Curry and Hacker 1990). Cattle and sheep in particular have had the greatest effect on these habitats due to their reliance on water (Reid and Fleming 1992) and their greater weight and harder hooves (Harrington *et al.* 1979).

The savannas of northern Australia have not experienced the high rates of mammal extinctions recorded in the arid zone, and have suffered less, in terms of range contractions, than any other region (Braithwaite 1985; Braithwaite and Werner 1987). Riparian zones in savannas are however, considered to be centres of diversity of non-volant mammals less than 5 kg (Braithwaite 1990); many species occur in higher abundance in riparian areas (Braithwaite 1990) and there is evidence that most reproduction and the most dominant individuals, occur with them (Braithwaite and Griffiths 1994). Braithwaite and Muller (1997) examined declines in several mammal populations in Kakadu National Park, NT. They derived an index of vulnerability and concluded that the species which appear to be most vulnerable are those with annual life histories and a strong preference for riparian areas. As their study was conducted in an area free of cattle, it did not examine the effects of grazing directly, but the authors noted that many of the positive features of riparian areas would be compromised by introduced grazers. The authors suggest that while grazing may be an important threat to the mammals reliant on these refuge areas, their observed decline in the absence of exotic herbivores suggests that other factors, in particular, long term changes in groundwater levels may also be important.

Probably the most important and dependent mammalian users of riparian zones in northern Australia are flying foxes (Woinarski, pers.comm.). Several species of flying foxes roost in and feed on, riparian vegetation and contribute to its maintenance through seed dispersal and pollination.

4.2.4. Reptiles and amphibians

There is a growing body of literature documenting the dependence of freshwater turtles on their riparian communities. Research in the Daly River, NT has shown that the Snapping Turtle (*Elsya dentata)* is far more dependent on riparian zones than previously thought. As well as relying on fruit inputs (particularly *Ficus* spp.) to the river as a major food source, high densities of turtles have also been found to forage in the riparian zones during the wet season (A. Georges pers.com). Turtles may also play an important role in the seed dispersal of riparian plants (R. Kennett, pers.comm.). Pig-nose turtles (*Caranettochelys insculpta*) lay eggs in shallow nests in riparian sand banks and as a result are especially vulnerable to trampling by stock (Georges and Kennett 1989).

Woinarski, pers. comm.). Sites will be sampled once during the next two years and will include all the sites sampled for the Monitoring River Health Initiative (see below), which experience a range of grazing pressures.

The CRC SDTS will also be undertaking an assessment of the vertebrate fauna associated with chenopod shrublands within the northern savannas. In this region, Chenopod shrublands are usually associated with intermittent wetlands and are highly sought by cattle, but are readily degraded by excessive grazing pressure. The project aims are to: document the conservation value of these blue bush swamps, examine the distributional patterning of their associated vertebrate fauna and briefly investigate the effect of grazing (J. Woinarski, pers. comm.).

4.1. Riparian flora

Plants are particularly useful indicators of grazing disturbance as they are abundant and diverse, and are the taxon most directly affected by grazing (Landsberg *et al.* 1996). Few studies have examined the effects of grazing on riparian vegetation in northern Australia, although the scant information currently available clearly indicates that cattle grazing has a negative effect on riparian vegetation.

A study is currently underway to determine the effects of grazing on the regeneration and persistence of riparian vegetation of the Ord River in the Kimberley, WA (N. Pettit, pers. comm.). The project aims to provide information which can be used for the restoration of degraded riparian zones. This project will use field surveys, soil seed bank studies and cattle exclosure plots and is complemented by additional field work on riparian vegetation in south west Western Australia. Preliminary results indicate a large effect of cattle grazing on species richness and structural diversity of the riparian zone, although there appears to be a less significant effect on the recruitment of overstorey species.

In the lower Burdekin region, continued grazing pressure also appears to be restricting forest re-growth in the lower floodplain areas of the East Barratta Creek (Lukacs 1995). Severe damage to riparian vegetation as a result of cattle access to water courses, has also been observed in streams within the Townsville Field Training Area (Pearson 1996)

4.2. Riparian fauna

Compared with riparian vegetation, slightly more is known about the effect of grazing on riparian fauna. However, given the small number of studies on vegetation, this is hardly reassuring.

4.2.1. Invertebrates

No past studies were found which dealt with the effects of grazing on invertebrate communities within riparian habitats. Whilst the CRC SDTS is currently using a range of invertebrate fauna as indicators of land condition in northern Australia, these study sites do not include riparian habitats (A. Andersen, pers. comm.). Previous investigations have found ants to be the most useful invertebrate indicators of grazing effects due largely to their relatively high abundance and diversity (Landsberg *et al.* 1996). Expertise is available for the identification of ants throughout northern Australia (A. Andersen, pers. comm.), and ants have already been used to examine the effects of other disturbances (e.g. introduced invertebrates) in riparian zones (B. Hoffman, unpubl. data). Ants may therefore also have potential as indicators of the effects of grazing in riparian habitats.

4.2.2. Birds

The vulnerability of birds associated with riparian zones in tropical savannas has been highlighted in a review of the conservation status and threats to savanna avifauna (Woinarski 1993). Although Woinarski laments the lack of information on which to determine the impact of grazing, it is worth noting that there is more documentation on the decline of birds in riparian zones than for other faunal groups.

Tidemann (1990) showed that the abundance of finches in tropical woodland in the NT declined with increasing grazing pressure. Although the study did not specifically examine riparian habitats, the results are "healthy" riparian zone. However, as cattle have natural tendency to focus on riparian areas, this compounds the effects of degradation elsewhere in the catchment. Cattle may also have direct effects on water quality through trampling of stream beds and the addition of urine and faecal material.

Observations on the effect of cattle on water quality come from studies of streams draining the Australian Army's Townsville Field Training Area (TFTA) conducted by the Australian Centre for Tropical Freshwater Research (ACTFR). They have undertaken several surveys of the water quality (and fauna) of the area over a period of several years. Water quality is known to have deteriorated during this time with the main direct effect being attributed to the pressures of cattle grazing (Pearson 1996). It was found that cattle wallowing and the addition of faeces and urine caused microbial contamination and elevated nutrient levels leading to eutrophication, particularly during extended dry seasons (Butler and Faithfull 1991); cattle faeces were a significant source of organic matter to the streams; cattle movement around streams has caused stream bank damage and increased turbidity; and re-suspension of sediments and nutrient elevation is also believed to have resulted from disturbance of the stream bed by cattle (Pearson 1996).

The TFTA is currently the site for several research projects related to impacts of military activities and grazing (J. Brown, pers. comm.). While these projects deal primarily with terrestrial systems, one project will investigate the effects of grazing on flora and fauna in riparian zones, and the downstream effects on water quality. This project is notable in that it uses very large plot sizes and is complemented by an additional project undertaking detailed catchment land mapping.

Grazing effects on water quality have been reported from elsewhere in Queensland. Lucaks (1995) described the poor water quality of grazed wetlands of the Lower Burdekin region, North Queensland.

The potential for cattle to affect water quality has also been noted in the NT (Fulton 1995; Finlayson *et al.* in press; Storrs and Finlayson 1997) but no data have been published. A study is currently underway to assess the water quality of three floodplain billabongs, with various degrees of cattle access, on the Reynolds River, NT (S. Townsend, pers. comm.). Findings so far indicate that the billabong with the greatest cattle access also had the highest nutrient and blue-green algae concentrations. However, not enough is known about the baseline water quality of the billabongs to attribute these effects to cattle access.

There are also reports from the Pilbara, WA, of how normally clear waters of dry season pools may become highly turbid as a result of trampling cattle (P. Davies, pers. comm.)

4. Riparian biodiversity

Riparian zones are recognised as critical habitats which link wetland ecosystems with their catchments. In northern Australia these habitats may represent only a small proportion of the landscape but are important for native wildlife, acting as corridors for movement and refugia during dry periods (Braithwaite 1985; Braithwaite 1990; Catteral 1990; Morton 1990; Braithwaite and Muller 1997). Unfortunately, riparian zones are also particularly prone to intense grazing pressures as they offer water for stock, shade and more palatable pasture species (Wilson 1990; Sattler 1993; McIvor *et al.* 1995). This intense grazing pressure may result in a loss of vegetation, particularly ground cover, trampling and soil compaction, stream bank erosion and the introduction and spread of weeds. This in turn can lead to high nutrient and soil inputs into wetlands, causing reduced water quality, increased sedimentation, silting of waterholes and stream channels, increased flood potential and loss of both in-stream and riparian habitat (Sattler 1993). Although these potential impacts, are widely reported in the literature, they are rarely supported by experimental evidence. Rather, they appear to be based mostly on casual observations.

The Cooperative Research Centre for Sustainable Development of Tropical Savannas (CRC SDTS) has a Riparian Habitats project proposed within its Biodiversity sub-program. Project details are still being finalised but the impacts of grazing management on riparian habitats, and subsequent effects on the aquatic biota will be a major focus of research (M. Douglas pers. comm). Study sites will include the VRD Region in the NT, but may also include areas in WA and QLD.

A study recently commenced through the CRC SDTS will involve the sampling of birds, adult dragonflies and plants (including weeds) in riparian and adjacent non-riparian areas from 120 sites throughout the NT (J.

Reviews of wetland and riparian management issues have consistently identified grazing effects as both an important threat and an area requiring more research. A national review of the major threats to the conservation of Australian wetlands (McComb and Lake 1988) listed "Grazing of wetland vegetation by stock and watering of stock in wetlands" as a direct threat, while other threats related to grazing included: effects of catchment clearing; river regulation; diversion and extraction of water from rivers and wetlands; weed invasion; wildfires and nutrient enrichment. The National Wetlands R&D Scoping Review (Bunn *et al.* 1997) listed "Grazing in wetlands" under the priority issue of Habitat Modification and noted specific impacts including; selective grazing of macrophytes, damage to banks and wetlands by trampling, contamination of water (e.g. increased turbidity, eutrophication and faecal contamination), and the introduction of weeds. The Habitat Modification background paper in the LWRRDC National Wetlands R&D Scoping Review (Bunn *et al.* 1997) reviewed the national literature on grazing impacts and included specific recommendations for future research and development. Aspects from this paper which are relevant to northern Australia have been included in this overview. At a national workshop on the ecology and management of riparian zones, degradation of riparian zones through grazing was ranked highly as an issue for research and management (Bunn and Pusey 1993).

Reviews relating specifically to northern Australia have also stressed the importance of grazing impacts as a threat to wetlands and riparian zones. In Queensland, the impact of grazing in wetlands has been described as varying from beneficial in some instances, to severely degrading in others. Inland areas are worst affected with the most widespread source of disturbance to wetland systems being erosion, siltation and plant invasions associated with over grazing, especially along watercourses, drainage lines and seasonal swamps (Blackman *et al.* 1993). The Western Australian chapter of "A Directory of Important Wetlands In Australia" (Jaencsh and Lane 1993) lists grazing as having a deleterious effect on wetlands through damage to river banks and riparian vegetation, degradation of catchments and associated increases in erosion, runoff and siltation. Recent reviews of the conservation status of wetlands in the NT (Finlayson *et al.* in press; Storrs and Finlayson 1997) include considerable discussion of the direct and indirect effects of grazing (i.e. impacts of weeds, fire regime, water regime and physical modifications) on wetlands and riparian habitats.

Recent reviews of riparian zone management in northern Australia have also placed particular emphasis on the effects of the grazing industry. Halse and Jensen (1993) reviewed the current ecological condition of the four drainage divisions recognised by the Water Resources Council in Western Australia. The Indian Ocean drainage division was found to have moderate to high levels of riparian zone disturbance which was attributed largely to grazing and subsequent erosion caused by cattle moving in and out of stream beds. The southern and eastern Kimberley (Timor Sea drainage division) has extensive land degradation due to grazing, especially on the river floodplains and stream banks. By comparison, in the north western Kimberley, where there is no pastoral industry, riparian zones are mostly undisturbed. Sattler's (1993) review of riparian zone management in Queensland and the Northern Territory highlights inadequate management practices resulting in overgrazing as having caused considerable damage to riparian zones in these states.

A recurrent theme in all these reviews — riparian or wetland; national or regional — is the lack of information on the effects of grazing. It is clear that while grazing is invariably considered a *potential* threat to wetlands and riparian areas, the lack of research effort makes it extremely difficult to assess the magnitude and extent of the threat.

3. Water quality

Removal of catchment vegetation through grazing, soil exposure, trampling and soil compaction leads to increased run-off, erosion and transport of sediments into rivers and wetlands. Increased levels of sediment and silt in rivers and wetlands from erosion and slumping of banks, has severe implications for vertebrate and invertebrate animals in addition to causing changes in river morphology. In extreme cases increased sediment loads can fill in water holes, totally destroying both in-stream and riparian habitat.

Riparian vegetation plays an important role in stabilising river banks and influencing water quality. The impacts of disturbances on water quality within a catchment may be reduced if wetlands are surrounded by a

1. Introduction

The effects of the northern Australian grazing industry on wetlands and riparian zones are considered below. They are discussed according to the issues which have been most frequently linked to grazing in previous reviews, and include both the direct effects of grazing, and effects of other practices associated with the industry. These include the effects:

- on water quality
- on riparian biodiversity
- on wetland biodiversity
- of weeds associated with grazing
- of fire management practices

Throughout this review the term riparian will refer to "that part of the landscape which exerts a direct influence on stream channels or lake margins and on water and aquatic ecosystems contained within them" (Bunn and Price 1993) and will specifically exclude floodplains. For the purposes of this review, the large floodplains of many of the rivers in northern Australia are discussed under wetlands rather than riparian areas. The term wetland will broadly follow the definition used by the Ramsar Convention: "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, including areas of marine water depth of which at low tide does not exceed six meters" (Davis 1994). However, the focus will be on natural wetlands and will not include discussion of marine wetlands.

To cover the full range of potential impacts of the northern Australia grazing industry, no attempt will be made to distinguish between the impacts of "grazing" and "overgrazing". The importance of drawing this distinction will, however, be discussed in conclusions and recommendations.

2. Previous reviews

In Australia, there have been numerous studies which refer to the impacts of grazing on native flora and fauna (see Morton 1990). The majority of these studies, however, refer to research into the effects of grazing on terrestrial ecosystems only (e.g. Morton 1990; Landsberg *et al.* 1996). While wetlands and riparian zones exist within the study areas of some projects and monitoring programs, few studies focus specifically on the effects of grazing on these habitats. Furthermore, there is a marked regional bias in the existing literature, with most previous studies having been conducted in southern Australia. These have often been conducted in areas under intensive grazing management, as opposed to rangelands. Despite the overwhelming dominance of grazing as a land use in northern Australia, very little is known about its impacts on wetland and riparian habitats.

Review 2

A REVIEW OF THE IMPACTS OF THE NORTHERN AUSTRALIAN GRAZING INDUSTRY ON WETLANDS AND RIPARIAN HABITATS

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Contents

Physical and nutrient factors controlling algal succession and biomass in Burrinjuck Reservoir

Dr Ian Lawrence,
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Objectives:

1. Assess the relationship between reservoir inflow, nutrient loading, mixing and drawdown, sediment desiccation, P and N in the water column, and algal biomass, composition and succession, for Burrinjuck Reservoir for the period 1976 to 1996.
2. Determine if the primary factors controlling nutrient availability are:
   - nutrient loading from river and seepage inflows
   - nutrient losses from discharge and sedimentation
   - nutrient re-mobilisation from the sediment
   - internal nutrient re-distribution due to mixing and flows.
3. Determine if the primary factors controlling algal biomass are:
   - retention time in the surface layer;
   - levels of available nutrients;
   - mixing conditions; and
   - temperature and light.
4. Determine if the primary factors controlling algal composition are:
   - nutrient composition (C/N/P/Si ratios);
   - euphotic to mixed depth ratios.

- Determine the algal availability of phosphorus in bottom sediments of the Goulburn River downstream of the three discharge points under oxic and anoxic conditions.
- Develop and test a non-specific sediment transport model incorporating particle settling and resuspension, coupled to a P-speciation model describing transformations between dissolved, particulate, and bottom sediment forms of P, to predict the downstream effects of discharges on streams.

Sources and delivery of suspended sediment and phosphorus to Australian rivers: Part A Radionuclides and geomorphology — Namoi catchment

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Objectives:
- Quantify the relative contributions of topsoil and subsoil to the suspended sediment loads in generic landform/use catchments using atmospherically-derived radionuclides (^{137}Cs, ^{210}Pb, ^{7}Be).
- Link radionuclides results to trace element and ^{143}Nd/^{144}Nd, ^{87}Sr/^{86}Sr data collected and analysed by C. Martin defining natural and anthropogenic sources of phosphorus.
- Assess the relative and absolute magnitudes of the anthropogenic and natural fluxes of phosphorus within the generic catchments. Relate the fluxes to land use and geologic and geomorphic variability in catchments.
- Generate a set of rules governing the behaviour of sources of phosphorus within a set of generic landuse/landscape type catchments.
- Develop a landscape analysis technique that relates the dominant sources of sediment and phosphorus to geomorphic attributes in catchments.
- Determine how geomorphic attributes affect the efficiency of delivery of sediment and P to streams.
- Present this information in a form useful to regional land care and community groups and to State and Federal agencies.

Sources and delivery of suspended sediment and phosphorus to four Australian rivers: Part B Nd and Sr isotopes and trace elements — Namoi catchment

Dr Candace Martin,
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ANU,
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Objectives:
- Identify the natural and anthropogenic (fertiliser) sources of suspended sediments and associated phosphorus using trace elements and naturally-occurring radiogenic isotope (^{143}Nd/^{144}Nd, ^{87}Sr/^{86}Sr) signatures.
- Assess the relative and absolute magnitudes of the anthropogenic (fertiliser) and natural fluxes of phosphorus. Relate fluxes to land use and geologic and geomorphic variability in catchments, in conjunction with Part A.
- Investigate whether the radiogenic isotope compositions of algae directly monitor the source of bioavailable P, in conjunction with Rod Oliver.
- Present this information in a form useful to regional land care and community groups and to State and Federal agencies together with Part A.

Management strategies for control of cyanobacterial blooms in the Fitzroy river barrage

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CANBERRA, ACT 2601

Objectives:

- To establish the role of flow, stratification, turbidity and nutrient dynamics in the development and persistence of cyanobacterial blooms in the Fitzroy River Barrage (FRB) by a combination of field measurements and modelling.
- To extend an existing predictive model of stratification and algal growth dynamics in rivers by incorporating nutrient dynamics, and to adapt and verify the updated model for the FRB.
- To use the model to investigate and select the best strategies for cyanobacterial control in the FRB.
- To assess the general applicability of the model to other temperate and tropical rivers affected by cyanobacterial problems throughout Australia.

Whole-lake biomanipulation for the reduction of nuisance micro-algae

Dr Vlad Matveev,
CSIRO Land & Water,
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CANBERRA, ACT 2601

Objectives:

- To conduct a long-term whole lake biomanipulation experiment by changing the fish community in a small lake or a water storage.
- To perform pre- and post- manipulation analysis of relevant plankton-associated food webs, taking into account seasonal and inter-annual variability.
- To investigate the mechanism of the effect of planktivorous fish on plankton community structure.
- To assess the effect of the manipulation on algal biomass.

Focus catchment projects with objectives or techniques relevant to northern Australian catchments

Algal availability of phosphorus discharges from different catchment sources — Goulburn-broken catchment

Dr Rod Oliver,
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Canberra University,
CANBERRA, ACT

Dr Ian Webster
CSIRO Land & Water,
GPO Box 821,
CANBERRA, ACT 2601

Objectives:

- Describe the chemical compartmentalisation and availability for algal growth of phosphorus contained within the discharge from a STP, an irrigation return drain and an agricultural catchment within the Goulburn-Broken system.
- Describe changes in the quantity of algal available phosphorus associated with suspended sediments from the different sources after laboratory simulation of biogeochemical processing (eg low oxygen/redox conditions).
- Measure longitudinal changes in the particulate and dissolved phosphorus concentrations immediately downstream of the three input sources.

1. Summary

This review broadly assesses the potential for salinization of soil and surface water, and for nitrate contamination of groundwater, as a result of tree clearing and the establishment of introduced pasture. In the case of nitrate contamination of groundwater, potential for contamination would mainly be associated with introduction of leguminous species, nitrate fertilizer not having had very much use in the grazing industry.

Potential for soil and water salinisation is regarded as existing in both Queensland and the Northern Territory and broad assessments of areas which are susceptible to salinization have been carried out but these represent only a first approximation. No relevant literature on the potential for salinity was found for north-west Western Australia. The major issue seems to be the extent to which groundwater recharge is likely to increase following clearing and/or the establishment of introduced grasses. Modelling work carried out to date suggests any increase in recharge is likely to be episodic. The potential for increased recharge is also likely to be highly variable for the different climatic regimes and landscapes across northern Australia, and further work to determine the variation in this potential is necessary to ensure development of sustainable land use practices. However, given that salinity can only occur where there is significant salt storage in the landscape, studies to determine the land types likely to be associated with such storages should not be ignored.

With respect to nitrate contamination of groundwater, some groundwaters in the arid zone and in Queensland have been found to have nitrate-N in excess of recommended levels set for drinking water quality. In one area of the arid zone, this contamination was attributed to nitrate leaching from termite mounds. The potential for nitrate contamination of groundwater under leguminous pasture does not appear to have been investigated. While it is considered unlikely to be a problem, the current study on *Stylosanthes* pastures being funded by the MRC will probably provide data that indicate whether there is potential for such contamination for several soils and climatic regions.

2. Potential for soil and water salinization

The potential for soil salinization occurs where salt is stored in the regolith (including aquifers) and where the hydrological regime is such that changes to the vegetation can so alter components of the water balance that there is an increase in groundwater recharge and rise in saline watertables. Of interest here are the changes that can be produced in the hydrological regime by practices associated with grazing management, in particular, tree clearing and the establishment of introduced pasture species.

Dryland salinity as a result of replacing perennial deep rooted trees and shrubs with generally shallow rooted and often annual plants, is widespread in southern Australia. The extent and severity of the problem is such that millions of dollars are now being spent in research, extension and on-ground remediation programs to prevent further degradation and to reinstate the productive capacity of now saline land. To date, dryland salinity in northern Australia has not developed to anywhere near the same extent as in the south. There are differing views as to whether this is purely because tree clearing has not yet occurred on the same scale in the north, or whether it is because the potential for dryland salinisation is much lower. One view is that the dominance of summer rainfall results in a reduced risk of increased recharge compared with the winter dominant rainfall of the south. This line of reasoning assumes that the high evapotranspiration rates in summer result in most rainfall being taken up by plants even if there is a change to a shallower rooting system. Other scientists, however, point out that factors in addition to evapotranspiration, influence soil water regime following clearing. In particular, rainfall regime (the amount of rainfall and sequence of rainfall events), soil permeability and soil water holding capacity are also important.

This section reviews what is known of the current distribution of dryland salinity in northern Australia and work that aims to determine the potential for development of dryland salinity in northern Australian environments. This work covers that investigating extent and distribution of salt storages, as well as that concerned with the distribution of landscape characteristics likely to increase the potential for increased

Review 3

SALINITY AND NITRATE CONTAMINATION OF GROUNDWATER

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Contents

Potential Outcomes:

1. Field tests of metapopulation theory as an organising principle for weed and pest management programs.
2. Design procedures for optimising public investment in weed and pest management programs.
3. Improved decision making aids for individual land managers and Landcare organisations.

Landscape Restoration (Indicators of Sustainable Landuse Program)

Dr Joel Brown,
CRC for the Sustainable Development of Tropical Savannas,

Background: Exotic weeds are a major threat to both the productive capacity and the native ecosystems of northern Australia. Because these invasions are recent in origin, much of the potential range has yet to be occupied. Even within the current range, many landscapes are occupied only by discrete subpopulations. There is a genuine opportunity for focussed management to both limit the spread and reclaim landscapes already invaded.

Over the past ten years, work by state and federal research agencies has identified techniques for both containing invasions at current levels and removing weeds from small areas. However, the application of these techniques is only sporadic because of high treatment cost/land value ratios and climatic variability. One way to improve the economic effectiveness is to lengthen the time-frame across which treatments are applied. By extending the time-frame, the cost in any one year can be reduced and risk can be minimised. However, by applying treatments to selected portions of the landscape over a longer period of time, reinfestation is a risk. This project seeks to overcome these problems by developing a new approach to planning and implementing landscape restoration strategies, tactics and operations by considering both ecosystem and invasive plant attributes and the technologies available. The project will use research theory and techniques developed from landscape ecology and spatial analysis to develop a better understanding of the impact of degrading processes and what are the most cost effective restoration techniques using weeds as a model.

Objectives:

1. Develop a computer based Geographic Information System of *Cryptostegia grandiflora* distribution, soil property distribution, infrastructure and topography in two subcatchments by June 1997.
2. Develop a mechanistic model of *Cryptostegia* invasion patterns based on dispersal attributes, habitat suitability and climatic patterns by June 1997.
3. Using the models developed in 1 and 2, test alternatives for management of *Cryptostegia* at the subcatchment (<500,00 ha) scale in two areas by December 1997.
4. In collaboration with local land managers in the test catchments, implement a program of field experiments to validate the model by March 1998.
5. Test the model with other weed species in other catchments by December 1998

Methods: The application of mathematical models to determine where and when woody weed populations are most vulnerable offers an opportunity to improve the basis for managing weed populations. This project will use mathematical models in conjunction with field-based research programs to parameterize and validate the models. Population biology (dispersal, seed ecology, seedling ecology, life histories) data has largely been collected and working models are available. Information on the local impact of various control technologies (mechanical, biological, chemical, fire) is also available and disturbance—population relationships are quantified. A collaborative project between CSIRO-DTCP, UQ and CRC-TPM is currently underway to use GENSECT to predict large scale (5 km^2) patterns of weed spread across the tropics in response to different temperature, precipitation, atmospheric chemistry and land management change scenarios. RIRDC has funded the work for three years (1995-1998).

The next task is to apply spatially explicit models to provide testable hypotheses for applying control technologies at the landscape scale. There has been success in the area of conservation biology via the application of meta-population models to identify the most vulnerable sub-populations of endangered species. The output of these models has been used to predict which sub-populations are most critical to maintenance of the meta-population. As yet, there have been no attempts to apply this modelling technique to local eradication of undesirable species. In addition, other models of the impact of the spatial distribution of disturbance (percolation, diffusion, semivariance etc) and the impact on ecosystems may provide improvements in the design and implementation of land restoration programs. Using these techniques has much potential as the weed species in question have relatively long lifespans, short seedbank lives, restricted dispersal ranges, recruit only episodically, and are reasonably easy to detect remotely.

ATTACHMENT 1 — CURRENT AND PROPOSED RESEARCH

Contact	State	Catchment/Region	Issue	Status	Organisation	Division
Douglas	NT	Alligator Rivers Region	Fire and aquatic vegetation	Current	NTU	CTWM
Douglas	NT	Alligator Rivers Region	Fire and macroinvertebrates	Current	NTU	CTWM
Douglas	NT	Alligator Rivers Region	Fire and riparian vegetation	Current	NTU	CTWM
Stowar *et al.*	NT	Alligator Rivers Region	Fish and erosion	Completed	ERISS	
Stowar *et al.*	NT	Alligator Rivers Region	Macroinvertebrates and erosion	Completed	ERISS	
Douglas *et al.*	NT	Alligator Rivers Region	Para grass	Proposed	NTU	CTWM
Jaensch	NT	Barkly Tablelands	Birds in Riparian	Completed	PWCNT	
Reid	NT	Central Australia	Birds in Riparian	Completed	CSIRO	
Whitehead	NT	Mary River	Grazing of wetland vegetation	Current	PWCNT	
Woinarski	NT	Micthell Grasslands	Birds in Riparian	Proposed	PWCNT	CRCSDTS
Woinarski	NT	Various	Birds in Riparian	Current	PWCNT	CRCSDTS
MRHI	NT	Various	Macroinvertebrates	Current	DLPE	
Dostine	NT	Various	Macroinvertebrates in Riparian	Current	PWCNT	CRCSDTS
Cheal	NT	Various	Plants in Riparian	Current	PWCNT	CRCSDTS
Haytesbury	NT	Victoria River District	Rehabilitation	Current		
Boekel	NT	VRD	Birds in Riparian	Completed	?	
Douglas		Various			NTU	CRCSDTS
Bunn and Davies	QLD	Bamboo Creek, Innisfail	Para grass	Completed	GU	CCISR
Arthington	QLD	Brisbane River	Macroinvertebrates	Completed	GU	CCISR
Arthington	QLD	Brisbane River	Water quality	Completed	GU	CCISR
Brown	QLD	Burdekin	Landscape restoration*	?	CSIRO	CRCSDTS
Lucaks	QLD	Burdekin	Grazing of riparian vegetation	Completed	JCU	ACTFR
Lukacs	QLD	Burdekin	Grazing of wetland vegetation	Completed	JCU	ACTFR
Lucaks	QLD	Burdekin	Water quality	Completed	JCU	ACTFR
Bunn and Davies	QLD	Cooper Creek	Algae trampling	Current	JCU/UWA	CCISR
Lorimer	QLD	Desert Uplands	Rehabilitation	Current	QDEH	
Rowley	QLD	Gulf	Birds in Riparian	Completed	CSIRO	
Williams	QLD	Townsville	Hymenachne	Current	QDEH	
Pearson	QLD	Townsville	Macroinvertebrates	Completed	JCU	ACTFR
Williams	QLD	Townsville	Para grass	Current	QDEH	QNPWS
Brown	QLD	Townsville	Riparian biota/water quality	Current	CSIRO	TA
Pearson	QLD	Townsville	Water quality	Completed	JCU	ACTFR
MRHI	QLD	Various	Macroinvertebrates	Current	QDPI	
Rowley	WA	Kimberley,	Birds in Riparian	Completed	CSIRO	
Woinarski	WA	Kimberley, Purnululu	Birds in Riparian	Completed	PWCNT	
Pettit	WA	Ord River	Riparian vegetation	Current	ECU	
Davies	WA	Pilbara	Water quality	Completed	UWA	
MRHI	WA	Various	Macroinvertebrates	Current	WAWA	

List of organisations and divisions

ACTFR	Australian Centre for Tropical Freshwater Research
CCISR	Centre for Catchment and Instream Research
CCNT	Conservation Commmission of the Northern Territory
CRCSDTS	CRC for the Sustainable Development of Tropical Savannas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTWM	Centre for Tropical Wetlands Management
DLPE	Department of Lands Planning and Environment
ECU	Edith Cowan University
ERISS	Environmental Research Institute of the Supervising Scientist
GU	Griffith University
JCU	James Cook University
NTU	Northern Territory University
PWCNT	Parks and Wildlife Commission, NT
QDPI	Queensland Department of Primary Industry
QNPWS	Queensland National Parks and Wildlife Service
TA	Tropical Agriculture
UWA	University of Western Australia
WAWA	Western Australian Water Authority
WRD	Water Resources Division

*** see description on next page**

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arrangement, that need to be re-established (for example, the particular vegetation composition and structure required for particular animal species). While many Landcare and other restorative programmes are underway, research is needed to provide a sound scientific basis for these schemes. Monitoring and assessment of the success of these programmes should also be a priority.

While any new research should be targeted to the specific needs of northern Australia, it should be done in the context of the relevant national R&D Programs — the National Wetlands R&D Program, the National Riparian R&D Program and the National River Health Program. In particular, new research should be consistent with the specific recommendations in the National Wetlands R& D Program Scoping Review (Bunn *et al.* 1997) for future R&D relating to grazing and weeds. Their recommendations are that R & D should: determine the effect of different levels of grazing on wetland structure and function; plan and develop integrated grazing systems; and determine sustainable stocking rates in different wetland types.

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Research is needed on the practical application of restoration techniques. Experimental trials and assessment of the success of different techniques, are essential for evaluating the costs and benefits of alternative methods.

10. Current and proposed research

A summary of current and proposed research into the effects of grazing on wetland and riparian biota and water quality is given in Attachment 1. Most of the studies listed have been undertaken in the Northern Territory and Queensland, with far fewer studies carried out in northern Western Australia. In the NT, the majority of listed studies are in the Alligator Rivers region, though few of the studies relate directly to grazing impacts. Most of these projects have been carried out by either the Parks and Wildlife Commission of the Northern Territory (under the auspices of the CRCSDTS) or the Northern Territory University. Most of the studies listed for Queensland have been around Townsville or in the Burdekin River Region. These have been carried out predominantly by the Australian Centre for Tropical Freshwater Research at James Cook University or through the Queensland Department of Environment and Heritage. Some projects have been carried out by the Centre for Catchment and In-Stream Research at Griffith University or the CSIRO.

In riparian habitats, most research has focussed on birds, while macroinvertebrates are the most commonly investigated taxa in wetland habitats. There have been surprisingly few investigations of the direct effects of grazing on riparian or wetland vegetation and very limited research into the effectiveness of different rehabilitation techniques.

It should be remembered that this is not an exhaustive summary of current and proposed research as not all organisations were able to respond within the time-frame of this overview. Therefore, these trends should be interpreted with some caution.

11. Conclusions

Clearly this report cannot provide a comprehensive assessment of the effects of the northern Australian grazing industry on wetland and riparian habitats. The extreme paucity of information means that it is only possible to highlight the potential effects of grazing and note those (few) studies where these effects have been demonstrated. Many of the studies reporting effects of grazing relate to situations where stocking rates were clearly unsustainable and overgrazing had occurred. There possibly are levels of grazing at which none of the potential deleterious effects are realised, or, there may be levels of grazing at which the benefits (such consumption of weeds) outweigh the adverse effects. However, on the basis of available information, it is impossible to determine whether this is the case. We therefore reiterate the recommendation of Bunn *et al.* (1997) that a priority for future research should be determining sustainable levels of grazing and cattle use in riparian areas. Levels should be such as to ensure the maintenance of biodiversity and ecosystem function.

Much of the literature on this topic is speculative or at best, based on casual observation. More effort needs to be placed on quantitative and preferably experimental approaches. Studies will often need to be conducted over large areas, as many of the potential effects of grazing on wetlands arise from use in other parts of the catchment. Of particular importance is the need for studies to be conducted not only over a year, so as to incorporate the marked seasonal variation within the wet-dry tropics, but for sufficiently long periods to include the considerable interannual variation in rainfall, particularly in arid and semi-arid areas. Encompassing the annual variation in rainfall is necessary as it determines the patterns of movement of both stock and native biota and their degree of dependence on wetland and riparian areas. It is essential to obtain information during the critical dry periods, when these habitats act as refugia for native fauna.

Every effort should be made to integrate studies on the effect of grazing on the physical and biological components of ecosystems. The expense of experimental work, particularly where it involves manipulation of grazing over large areas, is invariably high. Multidisciplinary approaches should be pursued, not only to maximize the use made of experimental procedures, but also to allow interactions between physical and biological components to be investigated.

Very often we do not know the most effective techniques for restoring or rehabilitating particular riparian areas and wetlands. Often we do not know the important characteristics, and their quantity and spatial

Effects on native fauna include:

1. suppression of small vertebrate populations on the flood plains, probably related to removal of ground cover;
2. no effect on the number of magpie goose nests, but a shift in distribution away from floodplain margins and possible adverse effects on dry season swamp refugia contributing to population decline; and
3. adverse effects on pig-nose turtle populations through trampling of nest sites and habitat destruction, resulting in negligible recruitment (Georges and Kennett 1989).

Most of these reported impacts are qualitatively similar to those discussed for cattle grazing. Certainly the observation by Skeat *et al.* (1995), that the effects of buffalo on one part of the ecosystem often compounded effects on others, is directly applicable to cattle. For example, in both cases, loss of vegetation and soil compaction both contribute to accelerated soil erosion, while soil compaction and changes in surface hydrology will affect the composition of the vegetation. However, perhaps the most devastating impact of buffalo — the creation of swim channels linking freshwater wetlands to tidal creeks that result in saltwater intrusion — is also the least likely to occur as a result of cattle grazing.

9. Repair of degradation

There appear to be few data available that enable assessment of the effectiveness of management practices to repair wetland and riparian habitats damaged by cattle grazing and use. Although there are a range of methods which may be useful in rehabilitation — from simply reducing stocking rates to reseeding and replanting — we do not know whether these procedures will be successful in allowing re-establishment of the ecosystem processes and landscape functions have been disturbed. Restoration of such processes is necessary for complete rehabilitation (Ludwig and Tongway 1996). As discussed elsewhere in this report, we have only a fragmented understanding of the effects of grazing on the ecological processes in wetlands and riparian areas of northern Australia.

In addition, successful and cost-effective vegetation re-establishment requires an understanding of the regeneration ecology of desired species (Ray and Brown 1994). For many species in northern Australia however, this basic information is very limited. For instance, the factors restricting regeneration of one of the most widespread trees in northern Australian savannas (*Eucalyptus miniata*), were only recently identified (Setterfield *et al.* 1993). This research has provided a basis for developing restoration guidelines for degraded savannas (Setterfield *et al.* 1993). There is no indication that restoration techniques necessary for wetland (or riparian) habitats are any better known (Cook and Setterfield 1995). The challenge is even greater for the re-establishment of fauna as this requires an understanding of the habitat requirements pf particular species as well as the successful re-establishment of such habitat.

Efforts to mitigate erosion in riparian areas, and elsewhere in catchments, have received most attention. A study which monitored the effectiveness of erosion control measures in the Ord River Catchment (P. Novelly, pers. comm.) found that while revegetation had been effective in much of the catchment, complete removal of stock was the only way to allow sufficient vegetation regrowth to control gully and streambank erosion. A study currently underway in the Desert Uplands (M. Lorimer, pers. comm.) will use experimental exclosures to examine how different land types can withstand grazing pressure and the management needed to restore degraded land to a useful level of productivity. The study is relevant to this review as it is being conducted in an area with soils susceptible to degradation, and in a catchment containing two significant wetlands — Lake Buchanan and Lake Galilee.

A noteworthy example of a cost-effective management technique for the protection of riparian zones was reported by Sattler (1993). The Heytsbury Pastoral Group have undertaken extensive fencing of riparian areas along the Victoria River, in the Northern Territory. Areas up to one kilometer wide have been fenced off from the river and off-stream watering provided. Stock are excluded from the riparian area except in times of drought, when the area is used to provide relief grazing. The company considers this management practice to have been cost neutral, with the initial expense being offset by savings in fewer bogged cattle, reduced time spent checking the river for stock and more efficient helicopter mustering. It is recognized, however, that fencing off large areas of riparian habitat may not be an option for much of the rangelands in northern Australia.