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Wetland management, processes and functions

RAMSAR'S FUTURE DIRECTIONS

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ABSTRACT

The Convention on Wetlands of International Importance (Ramsar Convention) is undergoing a period of transition. Since 1971, when it was first adopted, until recently, the Convention has to a large degree been viewed as a Euro-centred, waterbird-centred conservation agreement. Since the late 1980's the number of Contracting Parties has grown substantially to cover much of the globe, and while waterbird conservation is still prominent in the Convention, it has very strongly embraced the concept of ecologically sustainable, or wise, use of wetlands.

In the lead up to the 1996 Conference of Contracting Parties in Brisbane, Australia, the Convention is for the first time taking a strategic look at its future, and taking deliberate steps to consider how, as a body of increasing diversity and in the face of continued degradation and loss of wetlands, it can be used to promote the conservation of the world's wetlands.

Key features of this process are a growing recognition of the role of wetlands in the broader landscape and the need to tailor management accordingly, the need to foster the involvement of local communities in their wetlands, the need to improve the routine monitoring of the condition of wetlands and to expand wetland inventories, and the need to put in place appropriate management policies and practices at all levels of government.

Keywords: Ramsar Convention, wetland conservation, management planning, inventory, monitoring.

1 Introduction

The Convention on Wetlands of International Importance, more commonly known as the Ramsar Convention after the small Iranian town in which it was first signed in 1971, was the first of the modern global treaties dedicated to the conservation of an ecotype. In essence, the Convention provides a framework for international cooperation in the conservation and wise use of wetland systems.

Representatives of member States meet every three years at Conference of Contracting Parties to assess progress with implementation and to plan future directions for the Convention. In the intervening periods, responsibility for implementing the Convention rests with the Standing Committee, an elected body with representatives of each of seven global regions plus the host nations for the previous and next Conferences. The Convention secretariat is based at Gland, Switzerland, headed by a Secretary-General and a staff currently of about 12 people. As at December 1994, the Ramsar Convention has 85 Contracting Parties, whose territories cover some 75% of the worlds lands. By 1996 this is expected to reach 100 member countries.

This paper will briefly describe the Convention's past and its future directions. It will then focus on the research interests of the Convention in an Australian context by discussing the activities of the Convention's Scientific and Technical Review Panel, the 1996 Conference of

Parties, and activities of the National Wetlands Program of the Australian Nature Conservation Agency.

2 The Ramsar Convention - past and future

The Convention grew out of a realisation in Europe during the 1960s, that waterfowl (the northern hemisphere definition) populations were dwindling as a result of loss and degradation of wetland habitat. The four main obligations on Contracting Parties to the Ramsar Convention can be summarised as:

- nominating suitable sites as Wetlands of International Importance, and thereafter ensuring they are managed so as to maintain their ecological character
- formulating and implementing national land-use planning, which includes wetland conservation considerations, and as far as possible, to promote the wise use of all wetlands within their territory
- developing systems of wetlands reserves, facilitating the exchange of data and publications, and to promote training in wetlands research and management
- cooperating with other nations in promoting the wise use of wetlands where wetlands and their resources, such as migratory birds, are shared.

The text of the Convention itself has been modified on two occasions, in 1982 to establish a process for amending the Convention, and in 1987 to establish the Standing Committee, a budget, and a permanent Secretariat - the Ramsar Bureau. Contracting Parties now have the opportunity to develop and refine the emphases of the Convention.

Until the late 1980s, the Ramsar Convention kept a relatively low profile in the international arena. It was largely a technical forum for sharing knowledge on wetlands management, particularly focused on waterfowl, and particularly focused on Europe. While other more high profile international treaties came into effect, the Ramsar Convention to some extent remained 'behind the scenes'.

The historically low profile of the Convention should not be taken as implying it was not successful in working towards its stated purpose. Several examples exist of wetlands which have been protected largely owing to their status as wetlands of international importance. It is fair to say that some Contracting Parties may not have considered joining the Convention had it developed differently.

Some important changes have occurred to the Convention since the late 1980s. These include:

- establishment of Ramsar's Wetland Conservation Fund, specifically to support a variety of projects in developing countries
- establishment of the Montreux Record for Listed Sites where changes in ecological character have occurred, are occurring, or are likely to occur
- establishment of the Wise Use working group, and its successor, the Scientific and Technical Review Panel
- an increasing recognition of the range of values of wetlands and their important role in the broader landscape
- more refined understanding of what is meant by 'wise use of wetlands'
- recognition of the need to prepare and implement comprehensive management plans for Listed Sites

- recognition of the need for greater international cooperation for the conservation of migratory species
- the need to understand and quantify change in ecological character.

The rapid growth in the number of Contracting Parties reflects this broadening outlook - from 27 in 1984 to 85 in March 1995.

This period of transition and maturation of the Convention is continuing in several ways. The Standing Committee, on which Australia, New Zealand and Papua New Guinea are represented currently, is now preparing a strategic plan for the period 1997–2002 for consideration at the 1996 Conference of Contracting Parties in Brisbane. Australia, Spain, Kenya, Uruguay and Canada comprise the sub-committee of the Standing Committee which is preparing the draft of the strategic plan. Features of the plan are likely to include the following goals for the Convention during that period:

- expanded membership of the Convention, including most notably from Australia's perspective, Asia and the South Pacific
- to increase the number and diversity of Listed Sites
- to promote better management of wetlands in general, and especially Listed Sites; including the development of policy frameworks and information bases, catchment and local management plans and ongoing monitoring programs
- promotion of wetlands restoration and rehabilitation
- to assist the participation of local people in wetlands management, including better education and technology transfer
- to promote cooperation with other international Conventions, regional frameworks and development agencies.

3 Scientific and technical review panel

The means by which the Convention guides its development and priority setting is mainly through its triennial Conferences, including more recently, the referral of specific issues to technical groups for consideration. The first of these was the Wise Use Working Group commissioned in 1990 to develop explicit guidelines for what the Convention is attempting to promote by the wise use concept. The success of this Group prompted the establishment in 1993 of a permanent Scientific and Technical Review Panel (STRP). Dr Max Finlayson of ***eriss*** is the representative from the Oceania region on STRP. This group meets annually, reporting to the Standing Committee, and is at present addressing the following issues;

- the inclusion of fish habitat values as additional criteria for listing sites as Wetlands of International Importance
- preparing guidelines for the interpretation of 'ecological character' and how this can be monitored
- preparing guidelines for application of the Montreux Record
- preparing guidelines for the implementation of the Monitoring Procedure which provides expert advice to Contracting Parties which have indicated that a Listed Site is undergoing ecological change

The activities of STRP are a direct reflection of the Convention's broadening outlook, while at the same time demonstrating a recognition by the Contracting Parties that there is an urgent need to provide tools for improved management of Listed Sites.

4 1996 Conference of contracting parties

Australia is to host the next Ramsar Convention Conference of the Contracting Parties in Brisbane, from 19–27 March 1996. The Conference is being organised as a joint venture between the Federal and Queensland Governments and the Brisbane City Council, with the recently formed Australian Wetlands Alliance also represented on the Conference organising committee. It is expected that up to 1000 delegates representing some 100 countries will be in attendance, with additional non-member countries sending observers. This will be the first occasion the Conference of the Contracting Parties has met in the Southern Hemisphere.

In offering to host the 1996 Conference, Australia indicated its desire to see the 'wise use of coastal zone wetlands' as a major focus of the meeting. This is in recognition of the ever-increasing pressure these wetland types are facing from human activities globally, as well as in Australia and the Oceania region. By hosting the 1996 Conference, Australia hopes to build on the regional interest generated by the 1993 Conference at Kushiro, Japan, and attract the attention of the South Pacific countries which are notable by their absence from Ramsar's current list of Contracting Parties.

The theme for the host country's technical day of the 1996 Conference, is to be 'Coastal zone wetland management in Oceania'. It is anticipated that a number of keynote speakers will address the Conference on a range of issues, such as tourism impacts and the importance of wetlands to fisheries.

During the Conference there will also be two days of technical workshops and their themes give a further indication of the Convention's future direction and priorities. The themes are:

- Wetland policy frameworks
- Guidelines for the definition of 'ecological character' and monitoring changes to it
- Interactions with the Convention on Biological Diversity and the Global Environment Fund
- Management planning for wetlands
- Fish habitat criteria for Listed Sites
- Community-based wetlands management.

5 Wetlands in the wet/dry tropics

In the context of the wet/dry tropics of northern Australia, the following areas of technical investigation are consistent with the likely future directions of the Ramsar Convention:

- development of 'wise use' management techniques:
  - buffer zone definition and management
  - ecologically sustainable use of wildlife for commercially managed wetlands
  - ecological rehabilitation of degraded wetlands and control of threatening processes such as weed infestations, saltwater intrusion and tourism
  - wetland restoration methods

- catchment management techniques
- community-based wetland management, especially by indigenous Australians
- methodologies for environment impact assessment relating to wetlands

- wetlands inventory/monitoring:
  - focussing on areas not well covered or containing less well documented wetland types
  - development of rapid assessment techniques using new technology
  - development of new means to communicate the information (internet, CD-ROM...)
  - development of methodology which can include local communities
  - presentation of information in appropriate formats
  - development of methods for monitoring change in ecological character of wetlands which are able to distinguish between natural change and change instigated by inappropriate human use
- developing a better understanding of the range of values of wetlands, for example quantifying their significance as habitat for fish and other taxonomic groups habitats, maintenance of water quality, flood mitigation and so on,
- improved understanding of the migratory species utilising the east Asian-Australasian and other flyways,

A number of areas for social research into wetlands will also assist in meeting those goals:

- training programs for wetland managers and other interested groups to ensure adoption of new techniques
- development of more sophisticated economic assessment of the values of naturally functioning wetlands
- education and awareness raising programs to target landowners and community groups
- documentation of traditional uses and management techniques for wetlands

Other actions at a policy level concerning wetlands in the wet/dry tropics would be consistent with the Convention's future directions, including:

- encouraging expanded membership of the Convention in the Oceania regions
- improved policy frameworks for wetlands management
- improved cooperation with other international Conventions, regional frameworks and development agencies
- an increase in the number and diversity of Listed Sites
- increased commitment to the preparation and implementation of management plans for Listed Sites.

6 National wetlands program

From the perspective of the Federal Government, responsibility for coordinating implementation of the Ramsar Convention rests with the Australian Nature Conservation Agency (ANCA). Implementation of the Convention in Australia is by the ANZECC forum, with the Wetlands Network, comprising a representative of ANCA and each State and Territory nature conservation agencies, taking prime carriage of this responsibility.

ANCA's National Wetlands Program (NWP) is the principle means by which the Federal Government supports implementation of the Ramsar Convention. Apart from supporting the 1996 Ramsar Conference, the Program has the following priority areas for attention during the four years of funding allocated in the 1994/95 budget;

- preparation of management plans for all Australian Ramsar sites
- inventory projects which will contribute to the second edition of *A Directory of Important Wetlands in Australia*, planned for publication in 1996
- research and management projects designed to contribute information to the wetland manager's resource library being assembled by ANCA
- education and public information projects which foster public understanding of, and involvement in, the conservation of wetlands
- development of a Wetlands Policy for the Federal Government.

Funding for projects under priorities 1 and 2 are available only to appropriate State and Territory government agencies, however funds under items 3 and 4 are also available to universities, local government, community groups and non-government organisations. The fifth priority is being undertaken by ANCA. The level of funds available under the NWP for 1995–96 are not yet known. However, pending the outcome of the 1995–96 budget, priority areas for funding may be expanded to include;

- establish and service the National Wetlands Advisory Committee, whose functions will be to oversee the development a Federal Wetland Policy, and advise on implementation of the National Wetlands Program
- support the development of cooperative management arrangements with Aboriginal and Torres Strait Islander communities, local councils and other community groups for nationally significant wetlands identified in the *Directory*
- undertake curriculum planning and development for a wetland managers training course, based at Kakadu National Park, for Australia and south-east Asian, South Pacific countries.

7 Conclusion

The Ramsar Convention is undergoing a period of transition during which its historic emphasis are expanding to consider whole wetland ecosystems and values. In response, the number of Contracting Parties has grown considerably in recent years, and this trend is expected to continue. The Convention is set to consolidate this growth by adopting an agreed strategic plan at the Brisbane Ramsar Conference in 1996.

In terms of the Convention's future focus on research and management issues, these are likely to include advocacy of the total catchment approach to management planning, efforts to foster the involvement of local people in wetlands management, a more sound information and research base upon which to make management decisions on wetlands. The Convention is also likely to encourage more active development of appropriate policy frameworks by Contracting Parties. New priority areas are expected to be wetland restoration/rehabilitation, monitoring and techniques for environmental impact assessment. These are areas where it is hoped Australia may set an example to other nations.

QUANTIFYING THE ROLE OF WETLANDS IN CATCHMENT NUTRIENT DYNAMICS

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ABSTRACT

Wetlands have a variety of different roles, functions and uses. They are important for environmental stability. However, few of their attributes have been adequately quantified. Because human society tends to exploit ecosystems before they understand them, it is important that the impacts of exploitation be monitored as a means of improving understanding. Also, the application of research results or data derived from monitoring should recognise the design and purpose of the original investigations. These important general issues in resource management are explored with reference to the role of wetlands in catchment nutrient dynamics. Four levels of increasing complexity of research investigation are identified and compared with respect to research costs and management benefits. Choices for particular situations will involve trade-offs between the reliability of data and the cost of obtaining it, and between high-risk environmental management and sustainable management. Much current research on nutrient dynamics in Australia is seriously deficient.

Keywords: wetlands, nutrient dynamics, nutrient budgets, application of research.

1 Introduction

A variety of different roles have been ascribed to wetlands in general. For example, Maltby (1991) noted that wetlands have a number of functions that are essential for 'supporting plant and animal life and for maintaining the quality of the environment', and specifically cited functions, such as flood control, shoreline stabilisation, sediment, nutrient and toxicant retention and food chain support. Wetlands have also been identified as sponges that retain run-off from storm events, thereby mitigating floods (Stearns 1978, Williams 1990). This means they should then be able to release excess water slowly over time, thereby ameliorating dry periods between rain events. Also, wetlands are often sites for groundwater recharge/discharge (Mitsch & Gosselink 1986, Williams 1990), and are extensively used by waterfowl for breeding and for feeding during migration (Maltby 1991). They have a special aesthetic appeal and are widely used for particular forms of human recreation (Mitsch & Gosselink 1986), as well as being convenient environmental buffers between residential and industrial areas (Stearns 1978). Wetlands are of particular ecological significance in Australian catchments because of their highly variable climatic conditions, and are considered to function as:

- sites of high biodiversity
- systems capable of transforming chemical quality of water
- refugia for species in times of drought
- 'a mosaic in time and space providing continuity in an environment characterised by hydrological uncertainty'
- a link for ' the seasons' in a 'non-seasonal' environment

- 'hotspots of productivity in an old and weather-beaten landscape'

(Mitchell 1994).

This list of functions is by no means exhaustive and there can be no doubt of the ecological significance of wetland systems, or of their importance for environmental stability.

It is therefore a matter of considerable concern that so many wetlands in Australia have been drained or degraded, but in this respect wetlands are no different to many other Australian ecosystems that have been destroyed or damaged by human interference. The propensity for human communities to want to manipulate ecosystems before they know how they function and to cure supposed environmental ills before they have even been diagnosed properly, let alone understood, is largely to blame for this general situation. This attitude is deeply ingrained in the human character and is unlikely to change, in spite of growing awareness of the close link between the future welfare of humankind and a sustainable environment. Lack of knowledge and understanding is not seen to be a reason to avoid, or even to delay, exploitation of ecosystems for presumed economic gain, or even for the application of remedial measures to degraded systems. It is therefore important that, in such cases, the effects of the manipulation of the system be quantitatively monitored so that knowledge can grow through experience and the manipulative procedure removed if anything untoward is observed. The question of how much knowledge and understanding is necessary before an ecosystem is subjected to manipulative management should also be critically and realistically examined. For all these reasons, it is now urgent to formulate a systematic approach to the progressive development of research into threatened ecosystems which can be integrated with experience gained from sequential development in human management of those systems.

Given the ecological value of wetlands, it is also surprising that so little attention has been paid to the quantification of wetland functions. The intrinsic technical difficulty and the expense of making appropriate and reliable measurements is part of the explanation for this, but again, wetlands provide examples of the general tendency for developers to avoid the collection of information that may inconveniently impede the implementation of their proposals. Such information is costly to obtain and can have negative commercial value, so that by any definition it is seen as uneconomic!

It is our intention, in this paper, to illustrate these issues by reference to the role of wetlands in the dynamics of nitrogen and phosphorus in catchments. We list below the questions, for which answers must be sought, if the overall, long-term purposes of the community are to understand, sustainably utilise, and wisely manage wetlands with respect to these two nutrients.

- What quantitative measures of these nutrients should be taken?
- What should be taken into account when making these measurements ?
- How should the data be applied in management?
- What qualifications should be placed on the use of the data?
- How should the accumulated data be integrated to provide a better, more holistic understanding of these systems and their role in nutrient management?

2 The selection of quantitative measurements of nutrients

In simplest terms, the effect of wetlands on the dynamics of plant nutrients in catchments can be indicated by measuring the concentration of these nutrients in surface water entering and leaving wetland systems. For practical reasons in field situations, measurements of nitrogen (N) and phosphorus (P) are often lumped as Total N and Total P. Further refinement of these data can be obtained by measuring the different chemical species that make up these totals. For the purposes of this paper we have called these levels of investigation LEVEL 1a and LEVEL 1b, respectively (figure 1). However, it is very important to realise that such a data set does not measure the *actual* quantities of the chemicals moving in and out of the wetland in the water, and therefore does not truly reflect the *dynamics of nutrient movements* in the catchment. For these to be established, the volume of water, as well as the quantities of nutrients in it, must be measured on each sampling occasion and the actual weights, or loads, of N and P entering or leaving the system calculated. Again, analyses of the chemicals can be confined to Total N and Total P or can be split into the chemical species involved. We have called these levels of investigation LEVEL 2a and LEVEL 2b, respectively (figure 1).

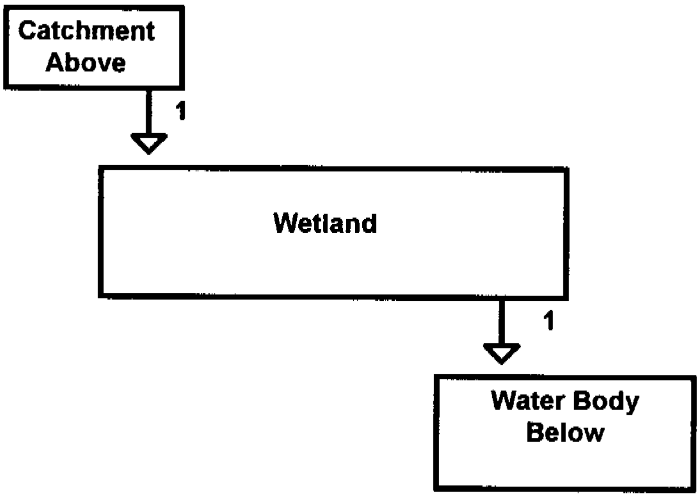

Figure 1 Study of movements of N and P in a catchment at LEVEL 1 and LEVEL 2 investigation. (1=Flow)

However, there are other mechanisms conveying nutrients in and out of the wetlands that would need to be investigated to determine their full role and significance in the nutrient dynamics of a particular catchment. These mechanisms can be systematically identified by examining the relationships between the wetland and its surrounding ecosystems with respect to processes that will move nutrients across the boundaries between them. There are two obvious ecosystems to consider: the adjacent terrestrial systems and the atmosphere. Processes between the latter and wetlands include the import of nutrients through rain and the export of nitrogen gas and nitrous oxide by gaseous diffusion (following their formation in the process of denitrification) and of ammonia by volatilisation. Processes of nutrient exchange between wetlands and terrestrial ecosystems, other than through the movement of surface water, include the import of nutrient in the faeces deposited in the wetland by birds and other animals that have fed outside the wetland, the export of material following grazing in the wetland by terrestrial animals and emergence of insects that have undergone the first part of their life cycle in the wetland, and the import and export of nutrient in groundwaters. We have called this level of investigation LEVEL 3 (figure 2). A research investigation at this level requires careful planning and some basic understanding of the systems involved. It would certainly be desirable to erect hypotheses for systematic evaluation and quantitative measurement and to discuss any proposed research with other knowledgeable wetland scientists.

In reality, the situation is much more complex than would be revealed by investigations at each of the preceding levels. For a start, the wetland itself, which is probably the most dynamic component of the system, is being treated as a 'black box' and processes which contribute and/or remove nutrients from the water flowing through the wetland are not being measured, even though they can have a profound impact on the quantities of chemicals retained or released by the wetland. Some of these processes involve transformations in the chemical nature of the nutrients themselves, while others cause the nutrients to cycle within the wetland. Both these kinds of processes must also be investigated if the system is to be understood. Wetlands are complex systems and the identification and structuring of the measurements that need to be taken to obtain a full understanding of the dynamics of nitrogen and phosphorus within the wetland and between it and adjacent ecosystems is a challenging task requiring a good basic understanding of the ecological nature of wetlands and their biota, the chemistry of nitrogen and phosphorus, the hydrology of wetlands and of groundwater, and the chemistry of water and of hydric soils. We have called a research study with this order of complexity a LEVEL 4 investigation (figure 3).

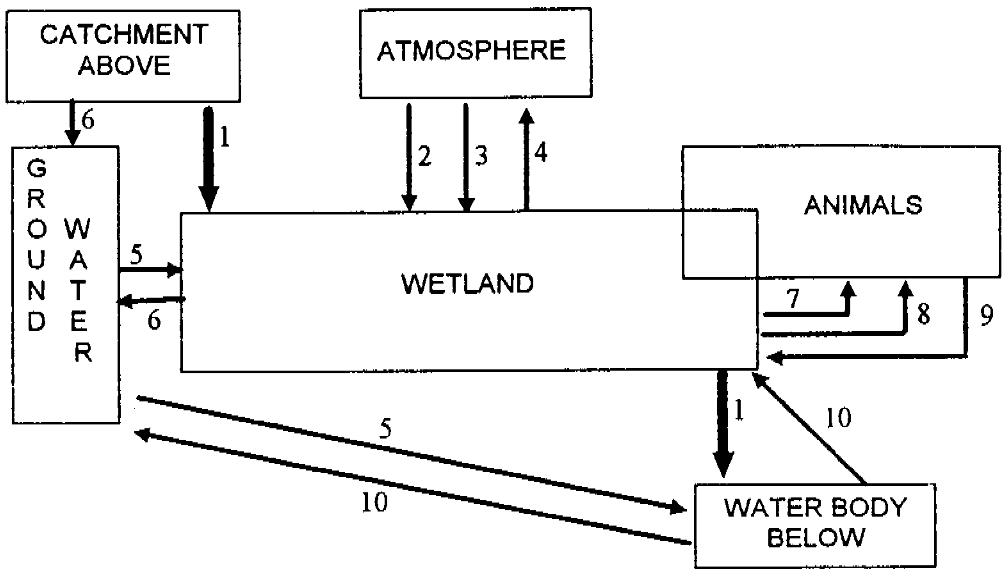

Figure 2 Study of movements of N and P in a catchment at LEVEL 3 investigation (1=Flow; 2=Precipitation; 3=Dust; 4=Gaseous diffusion, volatilisation; 5=Groundwater discharge; 6=Groundwater recharge; 7=Grazing; 8=Insect emergence; 9=defaecation, detritus, decomposition; 10=Floods.)

3 Planning investigations at the different levels of intensity

The factors that need to be considered in mounting each of the above levels of investigation will be discussed briefly with respect to our experience and the experience of others. Each of the levels will be considered in turn and then an attempt will be made to estimate the relative cost of each by assessing the number of person-years and major items of field equipment required for each study.

Level 1 investigations (concentrations only)

Investigations at LEVEL 1a require relatively little expertise, aside from that required to carry out chemical analyses of the water samples. Consequently, these investigations can be relatively inexpensive. However, investigations in which P is measured only as Total P, provide no information about the proportion of P that is biologically available and this can vary from 20% to 80% of the Total P (Oliver et al 1993). LEVEL 1b investigations overcome this shortcoming but because phosphate P is very labile, require that samples are either preserved, or subjected to initial chemical analytical procedures immediately after they are collected, and this adds to the expense.

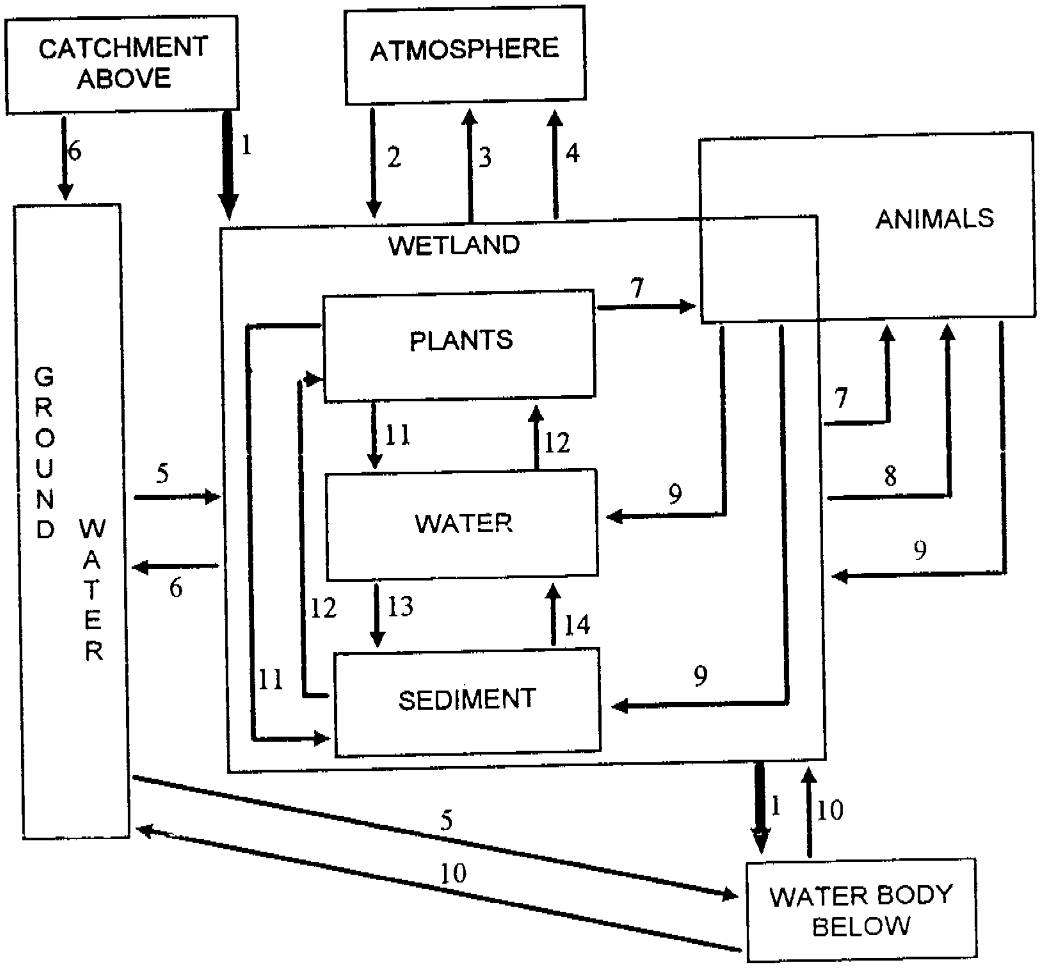

Figure 3 Study of movements of N and P in a catchment at LEVEL 4 investigation. (1=Flow; 2=Precipitation; 3=Dust; 4=Gaseous diffusion, volatilisation; 5=Groundwater discharge; 6=Groundwater recharge; 7=Grazing; 8=Insect emergence; 9=Defaecation, detritus, decomposition; 10=Floods; 11=Litter fall, exudation, detritus, decomposition; 12=Plant uptake; 13=Sedimentation, adsorption, precipitation; 14=Resuspension, desorption, solution, mineralisation.)

Notwithstanding the approach taken to analysis of P, LEVEL 1 investigations are basically ecologically unsound, as they do not assess all movements of N and P in and out of the wetland. Furthermore, as they are confined to measurements of concentrations alone, and loads are not calculated, they are likely to be misleading as well. Many papers and reports, even in the international literature, cite figures for *percentage removal of nutrients* by a wetland that are calculated from the decrease in concentration of a nutrient in the water flowing through a wetland. However, these figures reflect only the *percentage reduction in concentration of* *nutrients*. They would only be equivalent to percentage removal if there had been no change in the volume of the water and this is seldom if ever the case! Thus LEVEL 1 investigations are generally worthless for the understanding and management of nutrient dynamics, although millions of dollars have been spent on them in Australia and elsewhere.

Level 2 investigations (nutrient loads in surface waters in and out)

LEVEL 2 investigations may also be ecologically unsound for the same reasons as LEVEL 1. However, in practice, the flow of surface water in and out of the wetland is often the only significant mechanism for transporting nutrients between the wetland and adjacent ecosystems and when this is being assessed quantitatively, it may not be necessary to measure any other mechanisms. Nevertheless, this assumption should always be tested and, where necessary, the need for measurements of nutrient fluxes due to other mechanisms should be recognised. Furthermore, several studies have now shown that most mobilisation of nutrients in Australian catchments occurs during run-off events initiated by significant falls of rain (Cosser 1989, Cullen 1991, Raisin & Mitchell in press (a)). Consequently, regular measurements of water flows and collections of water samples for chemical analysis at fixed time intervals cannot provide a sufficiently complete assessment of nutrient dynamics for management, or for improved understanding. Finally, LEVEL 2a studies, which are based on analyses of P only as Total P, have the same limitations as LEVEL 1a studies with respect to interpretations of the availability of P. Unfortunately, it is difficult to combine flow-weighted event sampling with any field processing of samples immediately after their collection and separate studies of the dynamics of the different chemical species of P would be required.

Level 3 investigations (nutrient and water budgets)

The main benefits of LEVEL 3 investigations are that nutrient and water budgets for the wetland can be calculated. The data can also be used for modelling and thus lead to improved prediction of the behaviour of wetland systems under a range of catchment conditions. However, investigations at this level require a multidisciplinary approach and therefore the availability of several scientists of different expertise, who are capable of working together in a coordinated team. Different amounts of input would be required from different scientists and a high level of organisational proficiency would also be needed. Such studies are expensive and difficult to bring to successful fruition. Furthermore, LEVEL 3 investigations would not result in any improved understanding of nutrient dynamics within the wetland itself. Therefore, they could not contribute to many of the management decisions that would have to be taken with respect to the wetland, for example in relation to residence time, plant management, grazing, etc.

Level 4 investigations (includes wetland nutrient dynamics)

Wetland studies that include research on mechanisms of P and N dynamics are very complex in terms both of conceptual difficulty and of technical feasibility. Investigations at this level require a significant investment of skilled personnel and other resources, as well as a commitment to a long-term period of study. All these are in short supply in Australian science at present. Yet without such an approach, progress in understanding the role of wetlands in catchment nutrient dynamics will continue, at best, to occur by small increments, or at worst, to stagnate. Either way, a continuation of the current fragmented pattern of largely inadequate data collection, little of which are open to critical evaluation, is likely to be more expensive, both economically and environmentally, and less cost-effective than a single intensive, long-term study of relevant mechanisms in a representative wetland. Many of these mechanisms have already been studied to some extent, though usually in discrete investigations and often in other countries. This existing knowledge needs to be brought together and verified for a range of Australian conditions, or further refined in a composite study in which relationships between different components and mechanisms in wetlands can be observed and measured. A further advantage of such a study is that these relationships and mechanisms are likely to occur to some degree in every wetland. Thus it is not necessary to repeat such a study again and again in different sites. However, it must be done somewhere and it must be done well. A well-planned, adequately resourced, intensive investigation of a suitably representative wetland (or wetlands) would provide the best means of doing this for the benefit of Australia as a whole. However, such a study would have to be supplemented by investigations of different wetlands, preferably at LEVEL 3, in which these mechanisms would be verified for the different conditions that occur in Australian catchments (see also Raisin & Mitchell in press (b)).

Comparisons of the costs of 3-year studies at each level

Estimates of the costs of undertaking research studies at each of the levels described above have been made in terms of the number of person years that would be required to carry out a thorough study over a 3 year period. It is important to stress, however, that the period of 3 years has been chosen for comparative purposes only. Because of the high variability in Australian run-off hydrology, spatially and temporally, it is generally essential for appropriate data to be collected for a much longer period, provided that it is subjected to regular critical appraisal. Estimates have also been made of major equipment costs that would be required to set up studies for one wetland at each succeeding level of complexity. These estimates are displayed in table 1. They have been formulated on the basis of experience of similar studies: detailed costings have not been made.

Table 1 Comparative costs of studies of the dynamics of nutrient run-off from catchments at different levels of complexity

Investigation level	1a	1b	2a	2b	3	4
Personnel (person yrs)	2	2.5	4	5	8	18
Equipment ($1000)	5	5	15	15	25	50

Personnel costs include salary and routine operating costs for field and laboratory studies. Costs of chemical analyses are not included, as they would also increase in proportion to the increase in personnel. Equipment costs are for specialised field sampling equipment.

4 Conclusions and recommendations

There are a number of serious shortcomings in many of the investigations of the dynamics of nutrients in Australian inland waters. Studies which are centred on recording nutrient concentrations, and which do not include measurements of the quantities of nutrients that are being mobilised, are likely to be misleading and could contribute to errors of judgement in relation to both planning and operational spheres of programs to manage nutrients on the landscape. It is also essential to measure the fluxes of nutrients between various components of a catchment during rainstorms, as well as between such events. Routine fixed-interval water sampling does not do this and such data sets are virtually useless for management purposes. A further problem is encountered in those studies where Total Phosphorus is the only measure of phosphorus, as this value is a most unreliable indicator of the amount of P that is biologically available, especially in turbid water.

Unfortunately, the studies that would be required to overcome these problems are very expensive and are therefore seldom carried out, even in part. However there is no benefit in undertaking research that will not give reliable results, or that may be misleading. In such situations it is important that research planners examine the risks of contributing to management errors caused by unreliable or incomplete research data, and estimate the possible costs of such errors. This exercise would provide the justification to design a research program that will supply the requisite quantity and quality of data, or to place firm constraints on the extent to which the data can be applied, or to apply precautionary principles to management proposals. In some cases, it may be necessary to advocate a moratorium on development plans until research data of acceptable quality is available.

The situations in which such issues arise are often unique, complex and difficult to resolve. They can require a high level of ecological understanding and environmental sensitivity among parties that may otherwise have conflicting objectives. Preparedness to take carefully evaluated risks and an atmosphere of trust among the negotiating parties can often contribute to a solution, which could involve trade-offs between reliability of data and the cost of obtaining it, and a consequent balance between high-risk management and sustainable management of the environment. All these factors will need to be elucidated and negotiated before a sensible research program can be identified and commenced.

To many people such an approach would seem unrealistic but it must be realised that some of the most serious and expensive errors of judgement could have been avoided if decisions had been made following such an exercise of evaluation and negotiation. The primary difficulty is to judge when this approach is necessary and when it is not, and who should be involved in it. This question takes us into the political arena and adds another degree of difficulty that is beyond the scope of this paper. However, most, if not all, ecologists would counsel caution when the ecology of the system in question is not well understood, especially where any adverse consequences would be difficult to contain within the affected ecosystem. They would also advocate thorough monitoring of high-risk ventures, together with power to terminate the venture if previously agreed criteria of environmental damage are reached.

In this paper we set out to examine what research would be required to provide a reliable means of understanding and quantifying the role of wetlands in the management of nitrogen and phosphorus dynamics in catchments. Our examination clearly shows that it must be both intensive and long-term and therefore expensive. Any reduction in research effort in order to save costs or time would decrease the reliability of the research. The answers to the questions, which were asked in the introduction, provide a useful means of summarising our recommendations.

- The quantities of nitrogen and phosphorus entering and leaving a wetland should be measured as loads and not as concentrations. Total P is an inadequate measure of P for detailed understanding and for prediction of the biological impact of the P load. Thus estimates of the quantities of biologically available P must also be made. Ultimately, long-term multidisciplinary studies, at least of selected systems, are required to provide sufficient understanding for sustainable management.

- Nutrient loads must be measured during storm events; the biggest events are the most important.

- Application of the research data to management must take account of the reliability of the data as determined by its completeness in relation to the full range of seasonal conditions and the inclusion of all possible mechanisms for mobilising nutrients.

- Data collected from one site can only be applied to another site when the differences between the sites are taken into account. This is less important when the information relates to fundamental wetland mechanisms that have general applicability.

- Accumulated data from wetland studies should be used to model the nature and function of wetland systems in relation to their role in catchment nutrient dynamics. Such integration of the data would promote informed decision-making and enable identification of indicator parameters for monitoring.

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FISHERIES RESEARCH AND MANAGEMENT IN THE MURRAY–DARLING RIVER SYSTEM: SOME LESSONS FOR THE WET-DRY TROPICS

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ABSTRACT

Fisheries management in the Murray–Darling River system has three complementary objectives that focus on recreational angling, commercial fisheries, and conservation of fish resources. One of the key requirements for managing fish resources is an inventory of species distributions and abundance, and an assessment of related environmental factors. Streams throughout the catchment have been modified to provide water for agriculture for domestic and export markets. This creates a conflict for water between environmental requirements and other users. Most fisheries research addresses environmental issues to provide suitable conditions for self-sustaining fish communities which support strong recreational and commercial fisheries.

Wetland research for fisheries management concentrates on relationships between flooding and recruitment, to identify flow regimes likely to enhance recruitment in productive habitats. Environmental effects of alien species, most notably carp, and eutrophication also affect production of more desirable native species. Where native fish communities are seriously depleted, research must draw on inference from other systems to reconstruct environmental conditions most conducive to enhancing recruitment. Fish passage facilitates dispersal to and from key habitats and is an integral component of programs to enhance fish communities.

The Murray–Darling system has much in common with tropical wetlands in the way that flooding acts as a critical resetting mechanism for both physical and biotic components. However, greater interannual climatic variability in the Murray–Darling contributes to lower species diversity in fish communities, and longer temporal scales for ecological cycles. Regulation of rivers in both systems blocks fish migration, jeopardising the sustainability of fish populations. Interactions between native and alien species also constitute a threat to fish resources in freshwater systems in temperate and tropical Australia.

Keywords: wetlands, fisheries management, streamflow regulation, species diversity, floodplain ecology, controlled inundation, fish passage, native and alien species.

1 Introduction

Fisheries management in the Murray–Darling River system has three complementary objectives that focus on recreational angling, commercial fisheries and conservation of fish resources. Most fisheries research within this system addresses environmental issues to provide suitable conditions for self-sustaining fish communities that meet management objectives.

An inventory of fish species and their distributions and abundance is a fundamental requirement for future assessments of the condition of fish populations, and in determining appropriate priorities for investigating real or potential threats. NSW Fisheries is currently establishing an inventory of freshwater fish in NSW rivers for this purpose. Data on the composition of fish communities from this survey will be used to develop an Index of Biotic Integrity to assess the level of disturbance in different rivers (Harris 1995). Once an inventory has been taken, assessment procedures established and threats identified, elements most at risk, such as threatened or endangered species, can be monitored while keeping other elements in perspective.

Streamflow regulation to provide water for rural industries and domestic use has extensively modified riverine environments and associated wetlands in much of the Murray–Darling River system. The combined effects of river regulation pose the greatest threat to aquatic ecosystem processes throughout the basin. Other threats, such as toxic agricultural chemicals, can devastate local fish communities, but tend to be more restricted in the areas they affect.

2 Assessment of effects of river regulation

Changes to river habitats can be summarised as altered volume of streamflow, and altered seasonality of periods of peak and low flow. More specific changes, such as the height and duration of peak flows, rates of rise and fall of flood peaks, and the length of time between floods, fall into one of these two categories. Environmental changes caused by river regulation affect recreational and commercial fisheries through changes in reproduction and recruitment of both target species and prey species, and by impeding fish migrations.

Differences in species ecology lead to some fish species being more severely affected than others. For example, both silver perch (*Bidyanus bidyanus*) and golden perch (*Macquaria ambigua*) were once considered prime target species. However, in the River Murray at Euston between the early 1940s and 1990s, the relative abundance of silver perch declined by 93% whereas golden perch numbers declined by only 43% (Mallen-Cooper 1993). Silver perch have changed from being common to extremely rare throughout the system in a very short period of time. Reproduction and recruitment of both species is influenced by the timing of high flows, and both species migrate extensively within the major tributaries. Specific reasons for the dramatic decline in silver perch numbers are unclear. In contrast, increased stability of river flows has created favourable conditions for alien species such as carp (*Cyprinus carpio*). Carp numbers in the Murray–Darling Basin have expanded to the point where they seasonally comprise up to 91.8% of the fish community in the Murray catchment around Moira Lake, and 49.3% of fish collected from the Paroo, Darling, Murrumbidgee and Murray river catchments (Gehrke et al in press). Carp have also been implicated in habitat degradation and eutrophication, leading to cyanobacterial blooms (Gehrke & Harris 1994).

Wetland ecosystems can be managed to create favourable conditions for native fish by restoring elements of a natural flow regime to key habitats. However, knowledge of broader issues affecting fish communities is essential to identify critical environmental conditions and to establish realistic targets for restoring local communities. Where barriers to fish migration exist, provision of appropriate fishways or alternative solutions may be an essential prerequisite to re-establishing native fish communities.

2.1 Controlled wetland inundation

Early studies in the Murray–Darling river system by Lake (1967) and Mackay (1973) established the relationship between increases in water level and spawning for golden perch. Other species, such as Murray cod (*Maccullochella peeli*), did not require flood conditions to spawn, but still demonstrated improved recruitment when the spawning season coincided with flooding. These results were consistent with ecological models for other floodplain river systems (Welcomme 1985), and led to the development of a Flood-Recruitment model for native fish (Gehrke 1994). The model generated hypotheses to enhance recruitment of native fish by restoring natural inundation regimes in key wetland habitats and coincided with interest in artificial flooding of wetlands across several disciplines (eg Bacon et al 1993).

The success of controlled flooding depends on, among other things, the ability of fish at either the adult or larval stages to select floodplain habitats. Both golden perch and silver perch larvae have the capacity to detect environmental gradients and respond accordingly (Gehrke 1990a), but in artificial floodplain experiments, golden perch larvae avoided floodplain habitats because of poor water quality despite the greater availability of suitable planktonic prey on the floodplain (Gehrke 1990b, 1991). Indeed, Gehrke et al (1993) found that leachates from river red gum (*Eucalyptus camaldulensis*) bark, wood and leaf litter contained high concentrations of polyphenols which were toxic to fish larvae and juveniles. As river red gums form dense riparian forests along much of the floodplain of major tributaries of the Murray–Darling River system, there was potential for small controlled floods to inundate litter accumulated on the floodplain without flushing it away to dilute and disperse toxic leachates.

Controlled inundation of small areas (ca 0.5 Ha) of Millewa Forest on the floodplain of the River Murray revealed that alien gambusia, (*Gambusia holbrooki)*, and carp readily colonised newly-flooded habitats, but native fish generally remained in permanent habitats. Furthermore, the population of native Western carp gudgeon *(Hypseleotris klunzingeri)* in an adjoining billabong failed to spawn during the period of manipulated water levels. Poor water quality occurred only in isolated sites and was not considered sufficient to prevent native fish from entering floodplain habitats. Caged golden perch juveniles distributed throughout the flooded and permanent habitats showed no significant difference in survival except for two sites with poor water quality where no fish survived. However, growth of caged fish during the flood was greater in the remaining flooded sites and the billabong site than in the permanent creeks feeding the system. This experiment demonstrated that although the floodplain sites provided good conditions for survival and growth of native fish in summer, only alien pest species such as carp and gambusia were able to take advantage of this small-scale flood. Presumably, much larger volumes of water would be needed to establish whether the native fish community in this part of the system was still able to respond to favourable environmental conditions.

2.2 Structure of fish communities and environmental stability

Due to the failure of controlled flooding to enhance the local native fish community in a heavily regulated section of the River Murray, a broad scale study was designed to investigate recruitment patterns and nursery habitat requirements for native fish in the Murray–Darling system. Sites were selected in permanent river and lake habitats, and temporary sites in floodplain and ephemeral creeks in the Paroo, Darling, Murrumbidgee and Murray rivers. These rivers vary greatly in the degree to which flow is regulated by dams and weirs. The Annual Proportional Flow Deviation (Gehrke et al in press) calculates the degree of flow regulation among catchments for sites disturbed by regulation. The formula is based on the difference between monthly estimates of current flows and natural flows obtained from the Monthly Simulation Model run by the Murray–Darling Basin Commission. This measurement enables attributes of biotic communities to be compared among sites using a quantified measure of the degree of flow regulation as the causal, independent variable.

Fish communities in catchments increasingly affected by flow regulation show a reduction in species diversity such as Shannon's H' index. This response is consistent with the intermediate disturbance hypothesis (Connell 1978), which predicts that diversity approaches a minimum in extremely stable or frequently disturbed environments, with maximum diversity at some intermediate frequency of disturbance. River regulation reduces the frequency of low flows and truncates the peaks of moderately large flows, to the point where increased environmental stability results in lowered diversity.

Fish communities differ significantly among catchments. For example, the Darling River around Menindee and the Paroo catchment are both dominated by golden perch and bony herring, (*Nematalosa erebi*), but the Paroo contains more tropical species, namely spangled perch, (*Leiopotherapon unicolor*), and Hyrtl's tandan, (*Neosiluris hyrtlii*), which do not occur in the other catchments. Differences among catchments are influenced by a number of factors acting together, including increasing climatic aridity and less predictable rainfall to the northwest, increasing runoff and river regulation to the southeast, and latitudinal gradients limiting the southward spread of spangled perch and Hyrtl's tandan, while simultaneously limiting northward movement of redfin perch (*Perca fluviatilis*).

These differences have implications for management of fish resources and wetland habitats in different catchments. Catchment-specific management which recognises heterogeneity among fish communities, environmental conditions and the degree of habitat disturbance among catchments has not been extensively developed in existing management plans for the Murray–Darling Basin. Rather, fisheries management has followed the traditional approach for individual species within State boundaries, while habitat management plans are mostly developed on a site-by-site basis. Early results from studying fish communities in the Murray–Darling river system indicate that lacustrine communities vary less on a seasonal time scale than riverine communities. Disturbances such as floods or droughts tend to have less damaging effects on lakes than on rivers (Ryder & Pesendorfer 1989), with the result that lake fish communities are deterministic and develop a dynamic equilibrium. In contrast, riverine fish communities are subject to greater environmental variability that prevents the development of a dynamic equilibrium and leads to a more stochastic structure (Grossman et al 1982). During the short time scale of this study, the stability of lake habitats highlights their importance as refuges during drought. Subsequent floods then enable fish to disperse from refuge habitats and recolonise habitats which have dried. Despite these differences, fish communities display greater similarity within catchments than between habitats of the same type in different catchments.

2.3 Fish passage

Dams and weirs built for river regulation affect fish communities by blocking migration. It has been estimated that in NSW alone there are over 2000 weirs which act as barriers to fish migration in the Murray–Darling River system, of which only two, at Torrumbarry on the River Murray and at Boggabilla on the Macintyre River, currently have effective fishways (Mallen-Cooper pers comm). Many additional structures exist to divert water on a small scale, but these also impede active and passive dispersal of fish. Successful restoration of key fish habitats requires a native fish community to become established in the new habitat. However, barriers to fish migration both impede desirable species entering rehabilitated habitats, and also block dispersal from established communities to enhance populations in other parts of the system. There are four main options for improving fish passage within the Murray–Darling system: (i) build new fishways on existing and new structures; (ii) remove redundant structures; (iii) modify inefficient existing fishways; and (iv) provide suitable flows to enable fish to negotiate existing structures. Different designs of fishways and weirs, and the flow conditions peculiar to each stream require extensive monitoring to determine the most cost-effective option for priority barriers to fish migration.

3 Comparisons between tropical and temperate fish communities

Freshwater fish communities in tropical Australia contain more species than those in the Murray–Darling system. For example, the Gulf of Carpentaria drainage division contains approximately 50 native species compared to only 32 in the Murray–Darling. Although, at any one location in the Murray–Darling system, the maximum number of species is closer to ten. Aquatic ecosystems in tropical Australia are more variable on a seasonal basis than in semi-arid temperate climates of the Murray–Darling Basin. However, the lack of predictable seasonal rains creates greater annual variability in much of the Murray–Darling. From a management perspective, models of productivity based on seasonal variability in tropical floodplain river systems are likely to be more applicable in tropical Australia than in the Murray–Darling system.

The reliance of agriculture on a secure water supply has lead to extensive regulation of rivers in the Murray–Darling system, with numerous direct and indirect effects on fish communities. In contrast, rivers in tropical Australia are generally unregulated, but weirs constructed to provide pumping pools for domestic water supplies or to act as salt water barrages are relatively common and create problems for passage of migratory fish species. This has added implications in tropical systems where estuarine species may venture extensively into lower freshwater reaches, and conversely, where freshwater species may disperse through coastal waters. Other species also migrate between fresh and salt water habitats to complete their life cycle.

With the proliferation of alien species such as carp, redfin, gambusia, trout and salmon in the Murray–Darling system, native species have more competition from introduced species than in tropical Australia. In contrast, tilapia (*Oreochromis mossambicus*), has established several feral populations in northern Australia, but has yet to invade the Murray–Darling.

4 Summary

An inventory of fish species and their distribution and abundance is a fundamental requirement for assessing the condition of fish communities and wetland habitats. Once an assessment has been completed, real and potential threats can be identified, and elements most at risk, such as threatened species or key habitats, can be monitored while solutions to the threats are developed.

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THE ECOLOGY OF FRESHWATER ECOSYSTEMS IN THE ALLIGATOR RIVERS REGION: CURRENT STATUS OF KNOWLEDGE AND INFORMATION NEEDS FOR FUTURE MANAGEMENT

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ABSTRACT

Sound environmental management of wetlands is dependant upon a good understanding of ecosystem structure, process and function. The status of such information on the freshwater ecosystems in the Alligator Rivers Region (ARR) is indicated and suggestions are made on further information needs for future management. Whilst much information on the biodiversity of the ARR has been obtained, most of the freshwater systems adjacent to the region have not been examined for many groups of organism other than vertebrates and macrophytic plants. Consequently, it is difficult to evaluate the conservation status of other biota without more extensive distributional studies. The Arnhem Land plateau is very ancient so that permanent streams of the escarpment are likely to have been present for very long periods making it also likely that they may contain endemic elements in their biota. These areas should receive special attention in future inventory surveys. The absence of exotic fish in the region is noted as an increasingly rare situation in Australia and globally.

Much of the wetland habitat is highly seasonal and information on survival strategies used by the inhabitants is important for management. Migration has been shown to be an important strategy for some groups (waterfowl, fish and macroinvertebrates of seasonal stream channels). Information on strategies used by floodplain invertebrates is needed.

Whilst there is information on the community structure of the biota of particular habitats, little is known about the functional processes operating in these and other systems. Studies of trophic dynamics (food-webs, primary and secondary production) and nutrient flux within each system, and between systems, are needed to provide some idea of how different organisms interact. Diets of birds and fish are known but are not sufficient to construct food-webs for the ecosystems. Studies of other groups are required. The best-studied functional process examined so far is fish migration which can be seen as both a survival mechanism and a means of energy transfer between parts of a system. Information on the mechanisms involved in the contribution of the seasonal swamps to the production of economically important fisheries would be helpful. The extensive floodplain swamps comprise 98% of the wetland habitat, yet studies of the distribution of invertebrates and fish within them are lacking and will be needed to complement any work on trophic dynamics.

In seasonally-flowing creek channels on the lowlands, studies of the spatial and temporal dynamics of the macroinvertebrate community are needed. As in other stream systems, the frequently-flooded, riparian zone of these channels could play an important functional role but this has not been examined.

1 Introduction

A good understanding of the structure of wetland ecosystems and the functional processes operating within them is important for sound environmental management by providing the basis for the prediction of the outcome of man-made changes (Dudgeon 1992). In conjunction with environmental monitoring, this knowledge can help to develop, refine and validate monitoring processes, especially the choice of indicators and the interpretation of monitoring results. It can assist in development of cause-effect models of human impact and help improve the predictability of models of natural ecosystem function. Such knowledge should be an essential part of the information used for the development and assessment of alternative management strategies (INRE 1995).

Much of the study of wetlands in the Alligator Rivers Region (ARR) has been carried out by the Environmental Research Institute of the Supervising Scientist (***eriss***) in Jabiru and has been largely directed at the management of environmental effects of mining (Humphrey et al 1990). It was not directed at gaining a broad understanding of how the wetland systems function and, consequently, there are some major gaps in our knowledge, particularly questions concerning ecosystem processes, that need to be filled. In this paper we indicate the status of information on the structure and function of freshwater ecosystems in the Alligator Rivers Region and consider what further information would be of assistance for future management of these systems.

Biodiversity

Much information on the aquatic biodiversity of the ARR has been obtained (see reviews in Finlayson et al 1988, Humphrey & Dostine 1994) although some groups (eg cyanobacteria) still require attention. Nevertheless, with the exception of vertebrates and higher plants, the aquatic biota of most of the wetlands in areas surrounding the ARR have not been examined. Consequently, it is difficult to evaluate the conservation status of these organisms without further distributional studies. Research presently being undertaken as part of the National Monitoring River Health Initiative will help redress this situation for stream invertebrates in the Top End.

Coastal wetlands can wax and wane rapidly with changes in climate and many of their inhabitants are, of necessity, highly vagile species which are widespread. Also, the freshwater wetlands of the Northern Territory's coastal floodplains are very young (2-3000 y) (Woodroffe et al 1985). Hence it is unlikely that these wetlands would contain many specialised endemic biota. Sediments of the seasonally-flowing portions of the streams in the lowlands are comprised of unstable, shifting sands and are also relatively young (<6000 y) as the result of infilling of deep (10 m) Holocene channels (Roberts 1991). In contrast, the Arnhem Land escarpment is very ancient (Mesozoic). The permanent streams of the plateau escarpment are therefore likely to have been present for a very long time so that endemic elements in their biota may be present, either as relict species or through local speciation. Consequently, these areas should be targeted in future survey and monitoring work. The possibility of endemism is supported by the freshwater fish. Two freshwater fish species (Mariana's hardyhead *Craterocephalus marianae* and the black anal-fin grunter *Pingala midgleyi*) have a very restricted distribution, occurring only in the headwaters and lowland streams of the ARR and nearby western Arnhemland, and appear to be associated with the sandy substrates derived from the sandstone plateau. Also, several fish species (*Melanotaenia exquisita, M. trifasciata, Toxotes lorentzi* and *Hephaestus carbo*) have a very disjunct occurrence among the permanent escarpment streams (Bishop & Forbes 1990, Larson & Martin 1990) indicating that quite strong isolating mechanisms may occur, even among streams on the same river system. In contrast, most fish species in the floodplain zone are relatively widespread species. The absence of exotic species of freshwater fish is worthy of mention as it is an increasingly rare situation on a national and global scale.

The biogeographic situation for invertebrates is not well known. However, there are two undescribed species of palaemonid shrimp inhabiting permanent escarpment waters for which there are only a few site records at this stage (Humphrey & Dostine 1994).

Habitats and survival strategies

The wetland systems of the ARR encompass widely different habitats with different biotic communities. A large proportion of the total wetland area is highly seasonal (floodplain swamps, lowland billabongs and stream channels) as opposed to permanent water bodies (floodplain billabongs, lowland channel billabongs and escarpment headwater streams). Approximate values for Magela Creek are 210 km^2 seasonal habitats and 3 km^2 permanent habitats.

For the aquatic biota of highly seasonal habitats, strategies have evolved for taking advantage of the seasonally-available resources in the Wet season and persistence through harsh Dry season conditions. Many plants, and presumably some invertebrates, remain on site in the dry sediments as desiccation-resistant and/or dormant stages of the life cycle. Some species die out and recolonise these areas by stream or aerial transport from populations surviving the Dry season in permanent habitats (Paltridge 1992). The strategy used by birds (Morton & Brennan 1990) and fish (Bishop & Forbes 1991), and possibly some reptiles (such as filesnakes and crocodiles), is to undertake a regular migration of some form between seasonal and permanent habitats.

It is clearly important for conservation management to have some understanding of these survival strategies. The two most intensively studied wetland animal species are the economically important barramundi (*Lates calcarifer*) and magpie goose (*Anseranas semipalmata*) (Bayliss & Yeomans 1990, Morton et al 1990, Griffin 1995). The migratory movements and population dynamics of these species are quite well understood and management strategies to ensure their sustainable harvesting and conservation are in place. Whilst other species are not exploited to the same extent, similar information on many other species would be useful to provide an ecological basis for reserve design and management.

Fish migration between the floodplain and lowland stream channels of Magela Creek has been studied for 10 years by ***eriss*** as a potential method for detecting effects of mining (Bishop et al 1995, Pidgeon et al in press). Rainbowfish (*Melanotaenia splendida inornata*) and perchlets (*Ambassis* spp.) comprise over 90% of the migrants. The upstream migration of these species is much (at least 9 times) greater than the downstream migration (Pidgeon & Boyden 1993). As well as being a potential survival strategy for reaching permanent upstream habitats, this migration represents a significant net transfer of energy from the floodplain systems to the lowland/headwater sections of streams. On several days during the 1995 Wet season it was estimated that there was 0.5-1.0 tonnes/day of rainbowfish leaving the floodplain, these fish would contribute substantially to the diet of upstream predators. This information should be of relevance to environmental managers planning the construction of any in-stream or river bank structures. Further information on movements of other fish species between seasonal floodplain swamps and permanent billabongs would be useful for evaluating land-use practices and fisheries management.

In seasonal stream channels, most macroinvertebrates die out during the dry phase and recolonise the stream by downstream drift from permanent headwaters (Paltridge 1992). Information on the survival strategies used by invertebrates in seasonal floodplain habitats is needed.

2 Community structure

Most ecological studies conducted in the ARR have been of short duration and have described the structure of the biotic community in different wetland types together with their patterns of seasonal change (phytoplankton: Kessel and Tyler 1983, McBride 1983, macrophyte vegetation: Finlayson et al 1989, zooplankton: Tait et al 1984, benthic invertebrates: Marchant 1982, Outridge 1988, fish: Bishop et al 1986, 1990, in press, frogs: Tyler and Crook 1987, reptiles: Legler 1980, Shine 1986, birds: Morton and Brennan 1991). Longer-term studies are required to obtain an understanding of the natural variation in these communities and, in particular, the effects of the large differences in rainfall pattern from year to year. Such studies will help to identify important processes in the function of the system upon which to base sound management practices. Longer-term studies presently conducted by ***eriss*** focus only upon fish and macroinvertebrate communities in lowland habitats for the purpose of detecting any effects of uranium mining on aquatic ecosystems (Humphrey & Dostine 1994).

Ecosystem function

There is a major lack of data on the trophic dynamics of the different types of wetland. Relevant studies in this area can provide information about biotic interactions important in structuring animal and plant communities and can also enable food webs to be constructed. With such food webs, key interactions and species, or groups of species, may be identified for monitoring and assessment purposes. This information would also usefully serve to identify critical pathways for trophic transfer of contaminants through ecosystems.

Information on diets of birds (Morton & Brennan 1991), fish (Bishop et al in press) and reptiles (Taylor 1979, Legler 1980, Webb et al 1982, Shine 1986) has been obtained and detailed studies of the ecology of freshwater mussels have been carried out (Humphrey and Simpson 1985) but much other information is necessary before even crude food webs can be drawn up. Within each system the major carbon inputs (autochthonous and allochthonous sources) need to be identified and, where autochthonous primary production is important, biogeochemistry studies are needed to describe the nutrient dynamics operating in the system. It is then necessary to determine how the plant and detrital carbon is utilised by the complex of decomposer and consumer organisms. Carbon isotope studies which trace carbon sources though food webs could be very efficient at this. It is also very important to examine the exchange of energy/carbon and nutrients between the different sections (habitats) of the wetland system which occurs by two processes: active migration (fish and birds) and passive stream transport (nutrients as dissolved and suspended solids, detritus, algae and invertebrates). We know something about migration (see references above) and nutrient flux in the water mass (Hart et al 1987a, 1987b) but little about the other processes.

Perennially-flowing streams and permanent billabongs

Studies on the permanent waterbodies, including billabongs and permanent headwater sections of streams, warrant particular attention from managers and researchers as these are major refugial sites for aquatic biota during the Dry season. Many flow-dependant species reside here during the Dry season whilst some species of fish and invertebrates are restricted to these permanent lotic sections (Bishop & Forbes 1991, Humphrey & Dostine 1994). As with headwater streams elsewhere, there is evidence that allochthonous energy sources are important in these streams. Some fish populations here, for example, depend significantly upon terrestrial insects and fruit from riparian vegetation for their food (Bishop & Forbes 1991). As noted by Dudgeon (1992), investigations on longitudinal zonation patterns for entire stream ecosystems, as opposed to particular reaches or sections, are required to fully understand and manage tropical streams. Hence, lowland and floodplain wetlands of the ARR should not be studied in isolation of upland escarpment streams. The marked seasonal dynamics of phytoplankton, zooplankton, macroinvertebrates (including freshwater mussels) and fish in permanent billabongs have been recorded (see references above).

Seasonally-flowing portions of streams

In the seasonally-flowing portions of larger streams there is considerable information on fish communities but very little on the invertebrates, algae and macrophytes. As noted above, the source of the macroinvertebrates that reappear in the larger seasonal creek channels has been shown to be almost entirely by drift from the permanent upstream headwaters (Paltridge 1992). A study of the structure and seasonal patterns in the macroinvertebrate community of these channels is now needed.

There are many small streams on the lowlands that do not have permanent headwaters or billabongs to act as sources for recolonisation by macroinvertebrates and studies of their recolonisation processes are required. Burning of forests and grasslands is widely practiced as land management in northern Australia. The effects of fire on the communities of small seasonally-flowing streams of the lowlands has been examined by Douglas et al (in press, this volume).

The riparian zone of stream channels could play an important functional role in the dynamics of these ecosystems as in stream systems elsewhere (Bunn in press, this volume), but this has not been examined in the ARR. As the riparian forests can be flooded for quite long periods (up to 3 months) in some years, they could be a significant habitat for aquatic animals as well as having a major influence on the energetics of the ecosystem.

Floodplains

Floodplain wetlands present different problems to streams. Most of the aquatic research on the floodplain and lowlands has focussed on permanent billabongs. Apart from surveys of vegetation and birds, there has been very little work on the seasonal floodplain swamps. As these comprise 98% of the wetland habitat, this deficiency needs to be redressed. This will require studies of the distribution of invertebrates and fish in relation to the different plant communities. This would support any work carried out on trophic dynamics. Floodplain soils could be of special interest. The acid sulfate soils of the floodplain can cause natural fish kills by aluminium toxicity under appropriate slow flushing conditions in the early Wet season (Noller and Cusbert 1985). Fish kills in billabongs of some coastal floodplains also commonly result from sudden oxygen depletion caused by influx of organic matter and turnover of highly stratified water during storms (Townsend 1994). The significance of these kills to the dynamics of the fish communities has not been examined. As the water on the floodplain recedes during the Dry season, the soils dry out and become highly consolidated and compacted presenting an unsuitable habitat for invertebrates. Some indication of natural toxicity of the wet sediment to aquatic organisms was found in laboratory tests (Rippon 1994). Nevertheless, these soils support a large primary production in the Wet season and, presumably, also a large secondary production amongst the macrophytes and in the water column. Studies on carbon and nutrient flux would help to clarify the role of these systems as sinks and filters for materials imported from the catchment.

In large tropical rivers elsewhere, much of the production of fish is derived from the adjacent floodplain (Welcomme 1979). The higher production of barramundi in the Mary River than in some other rivers of the Top End could be related to much larger and more persistent freshwater swamps on the Mary River floodplain (Griffin in press, this volume). The seasonal pulsing of floods has been suggested as an important mechanism underlying this productivity by preventing stagnation and allowing rapid recycling of nutrients and organic matter (Junk et al 1989). Information on the mechanisms involved in the contribution of the seasonal swamps to the production of economically-important fisheries of northern Australia is required. They are undoubtedly important in recruitment processes for many species as well as providing major sources of food for fish.

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WETLAND HABITATS AND BARRAMUNDI

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ABSTRACT

Wetlands, both coastal and inland, are widely recognised as key elements in terms of fish production in the wet-dry tropics. Barramundi, Lates calcarifer, *is one of the most famous inhabitants of wetlands in northern Australia. It is the target of large numbers of recreational fishermen and is also an important commercial product. Production of barramundi is closely related to availability of highly productive wetland habitat. Coastal wetlands affected by tides are used as nursery areas by barramundi in the first few weeks of life. The availability of, and access to, such habitat is essential for maintenance of barramundi populations. This paper examines aspects of the relationship between wetlands and barramundi populations and makes suggestions for future research. Preliminary results of one study to identify and map barramundi nursery areas adjacent to Chambers Bay and Finke Bay in the Northern Territory are described.*

Keywords: nursery habitat, aquatic productivity, recreational fishing, commercial fishing, wetlands

1 Introduction

The wetlands of the Top End of the Northern Territory are undoubtedly of great importance to the aquatic productivity and hence fisheries. Species of major significance include barramundi, mud crabs and penaeid prawns (Griffin 1985). The influences of wetland habitats on these species will differ and there is little empirical evidence to enable the value of wetlands to fish resources to be determined. In some cases it is the wetland as physical habitat which is important and in others it is the primary productivity of the wetland. Historically, the difficulty has been in quantifying that importance.

It is widely accepted that the barramundi is an 'icon' of life in the Top End of the Northern Territory. Pursuit of barramundi is a very important recreational activity for many Territorians and an increasing number of tourists (Griffin 1982, 1988, 1993). Commercially caught barramundi is a high profile restaurant menu item throughout Australia, but is especially popular in the NT. Commercial yield of barramundi in the NT has stabilised at 4–500 tonnes per year under a strict management regime following over exploitation in the late 1970s and early 1980s. The current landed value of the commercial catch of barramundi and threadfin is around two million dollars. Recreational barramundi fishing is very significant in the wetland areas of the Mary River and in Kakadu National Park (Griffin 1982, 1988, 1993).

With the combined input of the commercial and recreational user groups barramundi is the generator of substantial economic activity in the NT and the Top End's wetlands are vital to the continuation of that situation. This paper will concentrate on the importance of wetlands to barramundi, possible impacts of wetland habitat modification on barramundi, and suggest areas of deficiency in knowledge which might be addressed.

2 Habitat requirements

2.1 General

Apart from coastal waters and rivers there are two wetland habitat types which are of vital importance to barramundi populations. The first is the supralittoral swamp habitats adjacent to the coast; areas inundated by the highest of spring tides. These swamps are utilised by barramundi from two weeks to several months old - approximately 5–50 mm total length (Moore 1982, Russell & Garrett 1983, 1985, Davis 1985, Griffin 1985, 1987). These areas are accessed by barramundi at the top of the spring tides in September through to December. In this highly productive and relatively safe environment they feed and grow rapidly. If good rains fall between tides this habitat is maintained and improved and growth and survival will be enhanced. If rain does not fall the habitat may dry up or become fairly inhospitable. In such circumstances survival will be poor. Through this mechanism there is a likely relationship between early wet season rainfall and barramundi spawning success.

As the wet season progresses many of the tidal nursery swamps merge into large swamps and river floodplains. The highly productive floodplain habitat provides refuge for barramundi and contributes nutrients to the estuarine system through runoff. Juvenile barramundi occupy the floodplain habitat for as long as possible and when it begins to dry out they leave and the majority will then migrate upstream as far as possible.

2.2 Nursery habitat study

Until recently specific barramundi nursery habitats had only been identified in the Shoal Bay area near Darwin and at Daly River. In September 1994 a project, funded by the Fisheries Research and Development Corporation, to identify and map critical barramundi nursery areas in the area from Cape Hotham to the Wildman River (figure 1) was commenced.

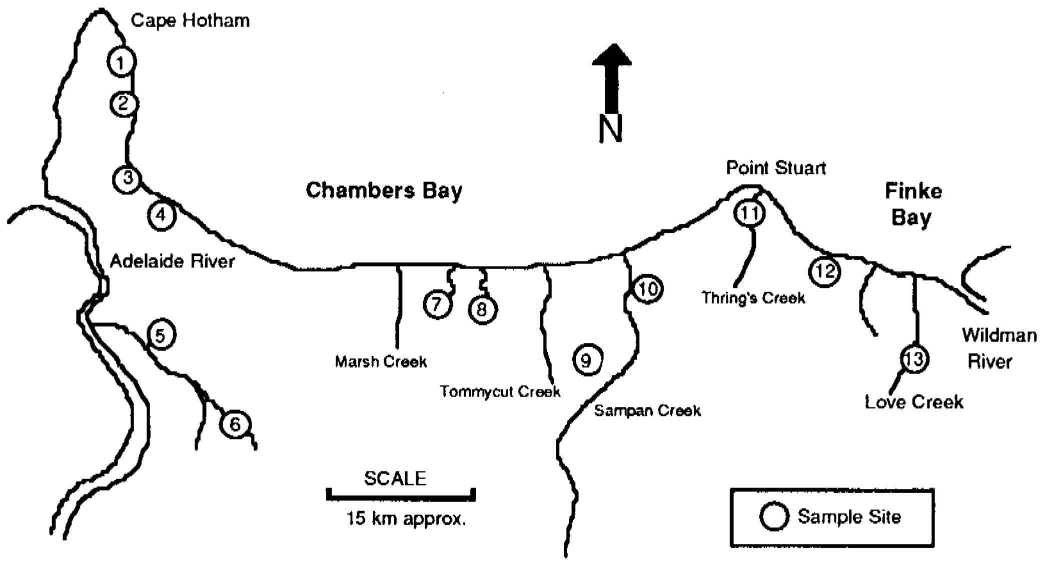

Figure 1 Map of barramundi nursery swamp sampling sites Cape Hotham to Wildman River

A total of 13 sites, selected on the basis of tidal access, proximity to the coast and vegetation types, were sampled using a simple hide trap and scoop net. Traps were set three days after the highest spring tide each month from September to January and checked two days later. Salinity, water temperature and water depth were recorded monthly at each station. Conditions in some of the areas sampled were most inhospitable in September and October prior to any rainfall and when tidal inundation was minimal. After December sampling was largely unsuccessful because of flooding of most sample sites. Barramundi were found at only three locations, two adjacent to Chambers Bay (sites 7 and 8) and one on the eastern side of Point Stuart (site 12) (figure 1). None was taken before November. The barramundi ranged in size from 5 mm to 25 mm approximately. At most stations there was a variety of other aquatic organisms collected, including penaeid prawns, mullet, tarpon, scats, and various other fish and invertebrate species. The capture of barramundi at a site indicates that it is used by barramundi. At some sites no barramundi were caught but species usually associated with barramundi (such as tarpon and scats) were abundant. The fact that barramundi were not caught does not necessarily mean that that area is not ever used by barramundi. The sampling strategy used does not permit any evaluation of the importance of the habitat sampled.

3 Habitat threats

In some areas of Australia the type of wetland habitat most vital to barramundi, the tidal nursery swamp areas, are threatened or have been destroyed by developments of various kinds, notably agriculture and tourism/residential developments. In the Northern Territory such threats are rare outside of the limited coastal urban areas. In the case of urban areas it is unfortunate that barramundi nursery swamps are also breeding areas for salt marsh mosquitoes, a fact which sometimes necessitates drainage of fish habitat to eliminate mosquitoes.

In the Top End there are potential threats to important barramundi habitat from floodplain pasture development (so called ponded pasture) and from programs to control saline intrusion in the Mary River region. It is unfortunate that works to prevent and reverse the dramatic intrusion of saltwater which is occurring (Woodroffe & Mulrennan 1993) might in some instances be preventing very small barramundi from gaining access to nursery swamp habitat. As the nursery swamp habitat is essentially at the interface between saltwater and freshwater habitats there is considerable potential for nursery swamp habitat to be 'rescued' from saline intrusion.

It is likely that one of the major effects of the rapid hydrological changes in the Mary River, from the fish's point of view, is not so much that the salt water is intruding further inland but that the freshwater now drains out of the system so much faster. This is likely to have an impact on overall system productivity as water is only on and running off the floodplain into the river and estuary for a few weeks rather than several months. There is substantial evidence that off-river water bodies have higher primary productivity than the main channels (various authors cited in Welcomme 1979). Whether or not the primary productivity of the Mary River system has been diminished by this accelerated drainage cannot be determined.

Large scale ponded pasture development has the potential to diminish the level of primary productivity reaching the estuary by retaining large volumes of water on the floodplain rather than allowing it to flow to the estuary. Many of the backflow areas of the Mary River floodplain are natural ponded pasture and as such are very valuable as grazing land. It is also reported from Queensland that on occasions juvenile barramundi have become trapped behind ponded pasture bunds and subsequently perished when the water dried up (S Hyland, QDPI, pers comm). In Queensland ponded pasture has been developed on saline coastal flats in some instances eliminating access by barramundi to tidal nursery swamps.

Other developments in wetland habitats also have potential to impact on barramundi and other aquatic resources. Recreational barramundi fishing has some potential to impact upon itself, firstly by depleting stocks if effort levels are high and management controls ineffective and secondly by overcrowding which reduces the value of the 'fishing experience'.

Grazing on floodplains also has considerable potential to impact on water quality and hence on aquatic resources. Flushing of large quantities of dung into rivers early in the wet season could add significantly to nutrient loadings. In some flow conditions this could lead to excess biological oxygen demand and cause fish deaths. First flushes have been shown to cause fish deaths through several mechanisms (Bishop 1980, Brown et al 1983) including excess BOD and aluminium toxicity associated with reduced pH. At the end of the wet season water bodies such as Corroboree Billabong usually become strongly stratified and oxygen stress is probably a normal condition during the transition from dry season to wet season. Such systems are not well equipped to cope with a sudden massive influx of quickly assimilated land derived nutrients in the form of dung. The activities of cattle feeding and drinking at the waters edge could also impact on overall productivity by reducing water clarity.

4 Research requirements

Many of the questions raised above relating to potential impacts cannot be answered effectively with the current state of knowledge of Top End wetland ecosystems. There would be benefits in further study of nursery swamps to precisely locate all areas used and to assess the relative importance of different habitats. Given the nature and remoteness of these habitats this work will be logistically very difficult. Comprehensive categorisation and mapping of such habitats on the basis of vegetation type, water chemistry, soil types, elevation etc should be afforded a high priority.

Basic data on primary and secondary productivity of floodplain, riverine and estuarine systems in the Top End should be investigated. If possible comparison should be made between the Mary River in its current state and an area such as Arafura Swamp and the Glyde/Goyder River system to quantify the effects of premature drainage/saline intrusion in productivity in the Mary. Comparison with the adjacent but apparently much less productive Adelaide River would also be useful.

In some wetland areas, notably Corroboree Billabong and Shady Camp Billabong on the Mary River, proliferation of aquatic macrophytes, particularly red lotus *(Nelumbo nucifera)*, has created some access problems for recreational fishing. A better understanding of the factors influencing the growth of aquatic macrophytes in Top End wetlands would be valuable. Studies of the ecological significance in terms of fish production of macrophytes would be useful.

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FIRE MANAGEMENT IN TROPICAL SAVANNA: THE EFFECTS ON STREAM BIOTA

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ABSTRACT

Despite the widespread use of fire as a management tool in the Top End, its effects on the aquatic biota are unknown. We present preliminary results of an experiment designed to assess the impact of two fire management regimes on the benthic macroinvertebrates and macrophytes in intermittent streams. The experiment was conducted at Kapalga Research Station in Kakadu National Park. Samples were collected from six intermittent streams: three from catchments burnt annually late in the dry season, and three from catchments left unburnt. Macroinvertebrates were sampled at two times during the 1992 and 1993 wet seasons and macrophytes were collected at the end of the 1993 wet season. Catchment burning had no significant effect on macroinvertebrate abundance. During the early part of the wet season, taxonomic richness was significantly greater in streams from burnt catchments. Ordination of the macroinvertebrate fauna suggests that the communities from the burnt streams were more similar to each other than the those in unburnt streams. Macrophyte species richness and abundance was significantly greater in streams from burnt catchments.

Keywords: fire, macroinvertebrate, macrophyte, intermittent stream, tropical, savanna.

1 Introduction

Fire management is a contentious issue throughout the world's tropical savannas (Gillon 1983, Stott 1986). In the Top End of Northern Australia, about 70% of the savanna woodlands are burnt annually (Braithwaite & Estbergs 1985). A number of studies have examined the ecological effects of fires on tropical savannas (Braithwaite & Estbergs 1985, Bowman et al 1988, Andersen 1991, Lonsdale & Braithwaite 1991) but these all focused on the terrestrial biota, and neglected possible impacts on the aquatic ecosystem. A few studies have investigated the effects of catchment burning on aquatic macroinvertebrates in temperate regions (Minshall et al 1989, Britton 1991b, Richards & Minshall 1992), but this question has not been addressed in the tropics.

We report the preliminary results of a study investigating the impact of fire management regime on the macroinvertebrate fauna and aquatic macrophytes of intermittent streams in the Northern Territory. We also provide some recommendations for future research into the impact of land management practices on the biota of intermittent streams in the region.

2 Materials and methods

The study was conducted at Kapalga Research Station in Kakadu National Park, Northern Territory. As part of the CSIRO Kapalga Fire and Water Project (Braithwaite 1990) the station was divided into 12 catchments, and replicate catchments were assigned randomly to one of four fire regimes. The catchments are 15-20 km^2 and each contains a first or second order intermittent stream, which typically flow from January to May and are usually dry from June to November. Our study compares six streams; three within catchments which have not experienced fires since 1987 (*Unburnt* catchments) and three from catchments burnt annually late in the Dry season (September) since 1990 (*Burnt* catchments). Four of these streams flow into the South Alligator River and two flow into the West Alligator River. Vegetation in these catchments is open woodland dominated by *Eucalyptus miniata* and *E. tetrodonta*, with an understorey of annual grasses, predominantly *Sorghum* spp.

During the 1991–92 and the 1992–93 wet seasons, the benthic macroinvertebrate fauna was sampled from the six streams. Four samples were collected from two pools on each stream using a suction sampler (Boulton 1985), modified for use on sandy substrates. Pools were sampled twice each wet season: ten days after flow commenced (Early flow) and ten days after flow ceased (Post flow). The fauna from each sample was identified to family level and counted. The total numbers of individuals and taxa was compared using five-way, mixed model ANOVA with Year (fixed), Flow-phase (fixed), Fire regime (fixed), Stream (random) and Pool (random) as factors. Ordinations of the faunal samples from the early flow of 1992–2 were carried out on log-transformed community data using multi-dimensional scaling (MDS) (Minchin 1987).

During the 1993–94 wet season, soon after flow had ceased, samples of aquatic macrophytes were collected from the same six streams. Five samples were collected from random points along the edge of each pool. A 0.25 m^2 frame was driven into the stream bed and all enclosed macrophytes were collected. This material was then returned to the laboratory where it was washed, identified and oven dried to a constant weight (90°C for 96 hours) before weighing. Total biomass and species richness per sample were compared by three-way mixed model ANOVA with Fire regime (fixed), Stream (random) and Pool (random) as factors.

3 Results

Macroinvertebrate abundance exhibited great temporal and spatial patchiness. Abundance varied between pools, streams and flow-phases, and with years (table 1). Catchment burning did not effect macroinvertebrate abundance. The number of macroinvertebrate taxa was far less spatially and temporally variable (table 1). Although there was no overall effect of fire, there was a significant interaction between fire and flow-phase (table 1). This was because samples from burnt catchments containing significantly more taxa than those from the unburnt catchments during the early flow phase (table 2), a pattern consistent in both years. Non-significant results in these analyses may be attributable to the low power in some of the F-tests. This arises, at least in part, due to the large scale of the experiment and the limited number of 'replicate' streams. The sample ordination for the Early flow period of the 1991–92 season shows that the faunas of three streams in the burnt catchments were similar, but those of whilst the streams in unburnt catchments differed more (figure 1).

Both species richness and total biomass of aquatic macrophytes exhibited effects of fire regime (table 1). The streams draining burnt catchments contained significantly more species of aquatic macrophytes (mean richness in burnt 5.92 spp/sample, unburnt: 1.0 spp/sample) and significantly more biomass (mean biomass in burnt: 2.04 g/sample, unburnt: 0.31 g/sample) than those draining unburnt catchments.

Table 1 Summary of significant effects from ANOVA for log abundance and taxonomic richness of macroinvertebrates and log biomass and species richness of macrophytes. Only terms that were significant for at least one variable are included

	Macroinvertebrates		Macrophytes	
	log Abundance	Richness	log Biomass	Richness
FACTOR	Sig. of F	Sig. of F	Sig. of F	Sig. of F
Fire	ns	ns	p<0.05	p<0.05
Flow	p<0.001	p<0.001		
Stream	p<0.01	p<0.005	p<0.05	p<0.05
Pool	p<0.05	ns	p<0.05	ns
Year*Flow	p<0.05	ns		
Year*Stream	p<0.05	p<0.01		
Year*Pool	p<0.05	ns		
Flow*Fire	ns	p<0.01		
Flow*Stream	p<0.001	ns		
Year*Flow*Pool	p<0.05	p<0.01		

Table 2 Ryan's test comparing the mean number of taxa for Early and Post flow phases in streams from burnt and unburnt catchments

Early flow, Unburnt	Early flow, Burnt	Post flow, Unburnt	Post flow, Burnt
11.9 <	13.9 <	16.5 =	16.7

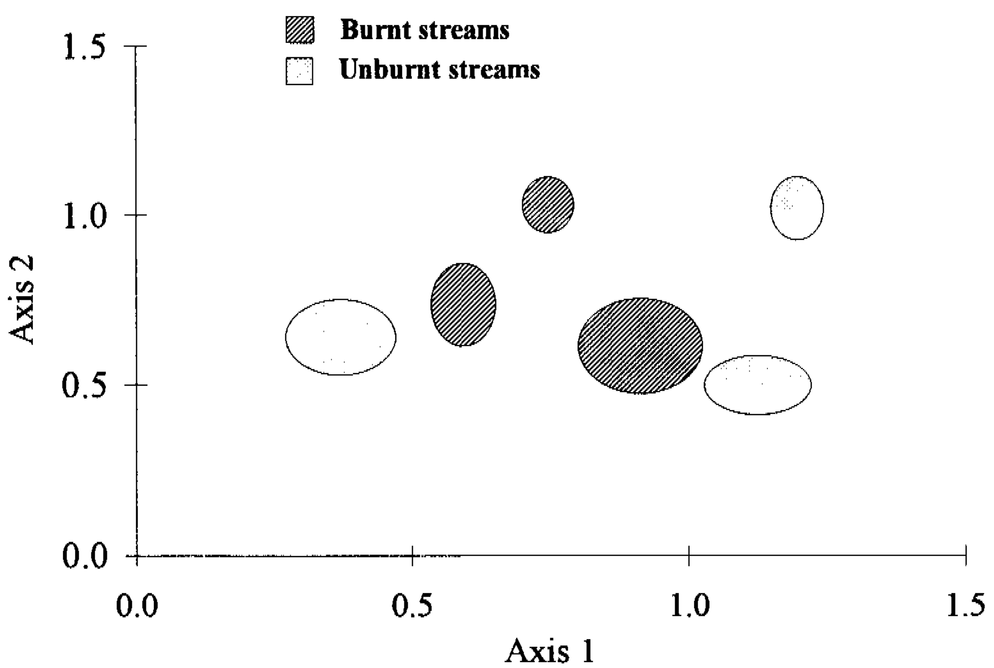

Figure 1 MDS ordination plot of faunal samples collected 10 days after flow during the 1991/92 Wet season. Ellipses represent the mean score (+/- S.E.) for all eight samples from each stream.

4 Discussion

The aquatic macrophytes in these intermittent streams showed a marked response to catchment burning, with both macrophyte richness and the total abundance significantly greater in streams draining burnt catchments.

The abundance of macroinvertebrates showed significant spatial and temporal variation but was not influenced by the catchment fire management regime. Macroinvertebrate richness was affected by catchment fire regime, showing higher richness in the burnt streams, though only during the period of early flow began. The difference was only about two taxa per sample, but this still represents a mean increase in the burnt streams of about 15%. Furthermore, additional work suggests that the effect is more pronounced when the fauna are identified to lower taxonomic levels (M Douglas, unpub).

The multivariate analysis indicates that the relationship between catchment burning and macroinvertebrate diversity is more complex when considered at a scale that incorporates a number of streams. In this case, whilst catchment burning may increase richness *within* streams, it resulted in a convergence of community composition *between* streams. In other words, richness apparently increased on a local scale but decreased on a regional scale.

The responses of aquatic macrophytes and macroinvertebrates result from changes in water quality after catchment burning. Douglas et al (1995) proposed that late dry season fires result in an early pulse of nutrients into these streams, probably due to the transport of ash in initial flood waters and consistently higher flood concentrations of total suspended solids, due to greater catchment erosion. Catchment burning also reduces the canopy cover of riparian vegetation (M Douglas, unpub). The biota may therefore be responding to additional nutrients, changes in sediment load, reduced shading or different litter inputs.

These preliminary results show that catchment burning does affect the aquatic biota of tropical intermittent streams, though the nature of the impact differs between the flora and fauna. Catchment burning may appear attractive to managers aiming to maximise macrophyte diversity, but this may cause richer but more similar macroinvertebrate communities, with an overall reduction in 'regional' diversity.

5 Future research directions

We suggest three main areas of future research into the impacts of land management practices on intermittent stream biota.

Firstly, further research needs to be conducted relating the effects of fire management to aquatic flora and fauna. Our study examines two extremes of fire management practices in the NT – no burning and annual late-dry season burning. Additional research may consider the impact of fires lit at other times of year (eg early dry season, early wet-season) or at different frequencies. The variation among streams to catchment highlights the necessity to conduct such work in a large-scale replicated design if robust answers are sought.

Secondly, though this work identified some *patterns* of response to fire management, it does not test the possible *processes* generating these patterns. Small scale manipulations of factors such as light availability, nutrients, algal biomass, sediment loads or litter inputs may provide explanations for the observed responses.

Finally, since late dry season burning can affect the aquatic ecosystem, it may be pertinent to examine the effects of other land management practices, such as grazing and agriculture, which result in similar alterations to the landscape eg vegetation removal and nutrient additions. This would be easier if future research identified the processes responsible for changes in the aquatic ecosystem. It would then be possible to predict the impact of other land management practices.

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WETLAND MANAGEMENT AND PROTECTION IN THE KIMBERLEY

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ABSTRACT

This paper outlines some of the issues relating to wetland management in the Kimberley region of Western Australia which impacts upon the Department of Conservation and Land Management – WA (CALM). CALM's responsibilities relate to vested estate and broader wildlife conservation matters on a state-wide basis. In order to place the issues in context, management of the Parry Lagoons Nature Reserve is discussed. This Ramsar and National Estate listed wetland is located to the south east of the town of Wyndham. The main value of the area recognised to date is its bird life, notably water birds. Many of the seven broad types of wetland areas are seasonal in nature. Issues affecting the wetland include; the damming of the Ord River, the need for greater documentation of the areas flora and fauna, exotic plants and animals, fire management, the need to document traditional knowledge about wetlands, illegal (or damaging) public activities and the impact and development of tourism.

Keywords: wetland management, Kimberley region, wildlife conservation, Parry Lagoons Nature Reserve, Ord River, fire management, tourism.

1 Introduction

1.1 Significant areas

The publication 'A Directory of Important Wetlands in Australia' (Australian Nature Conservation Agency) lists 13 major wetland areas within the Kimberley (Appendix I). This is by no means an exhaustive listing. Of these, seven are vested either wholly or in part in the National Parks and Nature Conservation Authority (NPNCA), or are adjacent to vested conservation reserves. A further four have proposed conservation reserves affecting them, five are listed under the Ramsar Convention and six are listed on the Register of the National Estate. The Prince Regent Nature Reserve, which surrounds much of the Prince Regent River System, is one of Western Australia's two UNESCO Man and Biosphere reserves.

Added to this are the vast array of estuaries, rivers and smaller 'landlocked' wetlands for which information is not available.

Apart from an estate management responsibility for the appropriately vested areas, and for conservation areas, this is usually the National Parks and Nature Conservation Authority (NPNCA). CALM also has a management and protection role in areas not controlled by the Department. This is because of obligations under the Wildlife Conservation Act and the general protection legislation which applies to all wildlife (flora and fauna) in Western Australia.

This paper will address issues applicable to CALM estate and in doing so will use as an example the Parry Lagoons Nature Reserve near the town of Wyndham in Western Australia's far north-east.

1.2 History

About 8 kilometres to the south-east of Wyndham lies the Parry Floodplain, the commencement of the Parry Lagoons Nature Reserve. Over several years there has been a consolidation of several water and conservation reserves to give an area of 36 000 ha. The last additions to the reserve occurred in 1992. The reserve is vested in the NPNCA and is managed on that authority's behalf by CALM.

The reserve was declared a Wetland of International Significance under the Ramsar Convention in 1990.

In the past the floodplain areas of the reserve were used as a holding facility for cattle, to rest them before sending them onto the meatworks at Wyndham and then for overseas export. An old pastoral lease, Goose Hill Station, was also included in the reservation.

1.3 Values

The broad types of wetland which can be found in this area include riverine floodplain, permanent river pools, seasonal streams, seasonal freshwater floodplain lakes, seasonal freshwater marshes, freshwater swamp forest and freshwater springs. Some billabongs are ten hectares in area and claypans and swamps can be 50–100 hectares.

The area attracts thousands of water birds, and it is the spectacle of its bird fauna that is a major attraction for the public. During the dry season, when freshwater can become scarce, large numbers and varieties of birds congregate on the gradually diminishing water bodies. Over 125 species of birds have been recorded from the reserve of which 77 are waterbirds including 22 which are listed under treaties. In years of good rainfall, the lagoons and associated seasonal wetlands are one of the major breeding areas of waterbirds in the Kimberley. Appendix II is an excerpt from 'A Directory of Important Wetlands in Australia', outlining the specific value to waterbirds of this area.

2 Issues

The issues affecting this area range in a broad spectrum from the physical environment to ecological processes to the sociocultural. Examples are:

2.1 Physical environment

In 1963 the Ord River was dammed at Kununurra (the diversion dam) and then in 1972 the Lake Argyle Dam, 52 kilometres upstream from the diversion dam, was completed. There is little information available on how this major project has or will affect the hydrology of the Parry Lagoons area. Have the groundwater levels been affected (and is it important if it has)? To what extent has the way in which the area floods changed?

The answers to these and other questions will help clarify managers and the public's perceptions of how we see the area now and its management requirements. Predictions could be made about how any changes which might be occurring will affect the conservation values of the area in the future and what management strategies are the most cost effective.

2.2 Flora and fauna

Most of the work documenting the values of the area have highlighted waterbirds. There is a need for extensive work on compiling a database on the flora (with associated mapping) and other fauna found in the area.

Exotic plants and animals are on-going management problems. Currently there are trials being put in place to document the effectiveness and impact of the aerial application of herbicide to control Noogoora burr. Cattle which stray into the area from surrounding lands are mustered on a regular basis. In comparison to the rest of northern Australia, the Kimberley and, in particular, its wetlands may well be only at the very start of increasing problems. The results of research in other places have direct application to the area.
These problems can usually be effectively managed by committing resources and the effects of control are tangible. The problems are physical, logistical and occasionally economic but usually there are attainable solutions and there is a sense of achievement for those concerned.

Management of fire in wetland habitats is a priority in most instances. The lagoons of the nature reserve are surrounded by grassland which carries fire very effectively and with an intensity that can result in scorching well into the vegetation of the lagoons. The effects this can have on wetland fauna, such as frogs, has been observed and it is the intention to at least minimise the rate of spread and the intensity of fire by protecting wetland with early season burning and strategic fire breaks until the true implications are understood.

2.3 Sociocultural

Native title

In 1994, the area was claimed by Aboriginal groups under the auspices of the Native Title Act and at one stage in late 1994, eviction notices were served on a group unlawfully squatting on the reserve.
In relation to Aboriginal issues concerning conservation estate, very little can be achieved due in the main to the present situation which has the State Government in opposition to the proposal from the Federal Government regarding Native Title. It is not CALM's role to assess the validity of native title even when it impacts on estate managed by this agency yet negotiation at some level must still take place to ensure the values of the area are understood and at least maintained. There is an urgent need to research and document traditional knowledge about wetlands.

Public use

Nature reserves in Western Australia are subject to legislation contained in the two main statutes under which CALM operates, the Conservation and Land Management Act and the Wildlife Conservation Act. There are difficulties in rationalising the requirements of these legislation when resource problems and dealing with the various viewpoints of user groups present obstacles to management.
Frequently there is a community perception as to what a Nature Reserve is for, which can differ with what a Conservation agency believes the use should be. Many people are of the opinion that over regulation is occurring, notwithstanding that often the protection that has been applied to areas such as Nature Reserves (in WA) has been in place for up to several decades. This is particularly so in the Kimberley as there are many competing interests where conservation lands are concerned and it can be time consuming to justify actions and carry out management activities that need to be conducted.

There are areas within the reserve which provide access through to the Ord River where fishing is a popular pastime, unfortunately this access is also through areas of quarantine for a declared weed, Noogoora burr *(Xanthium occidentale)* and frequently conflict occurs between the managing agencies and recreational fishermen. Joint management has its own special problems when legislative requirements conflict with management objectives (ie control of weeds).

Local community use continues on the reserve in a variety of forms mostly deemed unlawful under the present legislation. In particular, fire is used with little regard for the environment with large areas of the reserve being subject to wildfire at times deemed inappropriate by current knowledge and the area is crisscrossed with non-management tracks as frequently uncontrolled hunting takes place. There are also problems with litter associated with some of these activities.

Cattle and exotic plant encroachment are problems around some of the more permanent waterholes and these require other forms of management with liaison and physical controls usually effective.

At present there is no management plan in place to address these concerns and little inventory work has been able to be done. Given the situation where it is not possible to dedicate staff and appropriate resources to carry out this work due to the needs of the Kimberley Region as a whole, many issues are dealt with on a needs basis.

Tourism

Wetlands are attractive to tourists in northern Australia, due to the features they present, particularly local and visiting wildlife. There is a world trend to experience and promote 'eco tourism'. It is expected that tourist visitation will continue to increase at Parry Lagoons. Little work has yet been done on the issue of tourist impact. Frequently the areas that have been set aside or proposed for reservation are usually able to provide the best experiences because they have been protected either by legislation or simply by remoteness. Managing this burgeoning industry will be a challenge well into the future and will no doubt involve lengthy negotiation and sensible compromise.

Given the above-mentioned represent several of the main issues that present protection concerns, it is possible to identify that there is a direct tie-in to the management functions that need to be addressed to achieve satisfactory conclusions to them.

Resolutions for most of these issues are far from being achieved, however in some cases, progress has been made.

Every agency has a charter which attempts to set a clear direction for the functions it fulfils. It sounds simple but frequently when there are multiple users of conservation estate there can be conflict and it is important to be in a position of knowing, if not all the facts, then as many of them as possible. Being in this position helps justify plans of management and protection strategies and enables negotiation and consultation to proceed smoothly.

There are many opportunities for, and benefits of, a high level of communication between researchers and managers across the broad spectrum of issues in northern Australia such as wetland management and research.

Appendix I

1. **Lake Argyle**

   The Carr Boyd Ranges, on the western side of the lake and some islands within the lake have been proposed to become a National Park.

   The area is listed under the Ramsar Convention.

2. **Camballin Floodplain**

3. **Drysdale River**

   The area of importance has been described as within and adjacent to the Drysdale River National Park.

4. **Geikie Gorge**

   This area is entirely within the Geikie Gorge National Park. The area is included on the Register of the National Estate.

5. **Lake Kununurra**

   The Packsaddle Swamps, a small area at the northern end of the lake, have been proposed to be reserved for nature conservation to be managed by CALM. The area is listed under the Ramsar Convention.

6. **Mitchell River System**

   The lower reaches of the Mitchell River and adjacent catchment have been proposed to be added to the conservation estate.

7. **Ord Estuary System**

   Various parts of this system are within Nature Reserves.

   The area is listed under the Ramsar Convention and is included on the Register of the National Estate.

8. **Parry Floodplain**

   Most of the area is a Nature Reserve. The area is listed under the Ramsar Convention and is included on the Register of the National Estate.

9. **Prince Regent River System**

   Surrounds of the estuary and river system are mostly within the Prince Regent Nature Reserve.

   The reserve is a UNESCO Man and Biosphere Reserve and is included on the Register of the National Estate.

10. **Roebuck Bay**

    This area is proposed to become a marine park. The greater part of the site is listed under the Ramsar Convention.

11. **Roebuck Plains System**

12. **Tunnel Creek**

    This is within the Tunnel Creek National Park. The site is included on the Register of the National Estate.

13. **Windjana Gorge**

    This is within the Windjana Gorge National Park. The site is included on the Register of the National Estate.

Appendix II

The seventy-seven (waterbird species) include four darters and cormorants, fourteen herons and allies, fourteen ducks and allies, seven rails, twenty-four shorebirds and four terns. Rare species: Up to twenty-four Garganey *Anas querquedula* have been counted; thirty-seven Freckled Duck *Stictonetta naevosa* were recorded on the marshes in March 1988; a Pectoral Sandpiper *Calidris melanotos* was recorded in May 1986; and a Long-toed Stint *C. subminuta* was seen in December 1984. Painted Snipe *Rostratula benghalensis* are found more often at this site than anywhere else in WA. This is the only confirmed locality in WA for Zitting cisticola *Cisticola juncidis*, it breeds in the area and is widespread in the wetland grassland.

Breeding

Eight species found breeding in recent surveys; several others apparently breed at the site but there have been no systematic surveys of breeding. Magpie geese breed in sedgeland, mainly in the south of the floodplain, in wetter years and this is then the largest breeding concentration in WA. At least one breeding colony of egrets and herons exists in low closed-forest around swamps in the south-east of the site; there is little published information on this. Other breeding species include Darter *Anhinga melanogaster*, Comb-crested Jacana *Irediparra gallinacea*, Purple Swamphen *Porphyrio porphyrio* and (in tussock grass) Yellow Chat *Ephthianura crocea*.

Migration stop-over

Fifteen migrant shorebird species occur. The most abundant species are Little Curlew *Numenius minutus*, Sharp-tailed Sandpiper *Calidris acuminata* and Oriental Pratincole *Glareola malidivanum*. The site supports high numbers of Wood Sandpiper *Tringa glareola* (national rank 1) and Swinhoe's Snipe *Gallinago megala*.

Roosting

Egrets, other herons and magpie geese roost in trees within or fringing the floodplain billabongs and some marshes. Plumed Whistling-Duck *Dendrocygna eytoni* often roost at the west end of Marglu Billabong.

Numbers

The highest number of waterbirds counted was 27 000 in May 1986; more than 20 000 probably occur annually. The most abundant species are Plumed Whistling-Duck *Dendrocygna eytoni*, Glossy Ibis *Plegadis falcinellus*, Red-Kneed Dotterel (national rank 1), Little Curlew *Numenius minutus*, Black-winged stilt *Himantopus himantopus*, Australian Pratincole *Stiltia isabella* and Masked Lapwing *Vanellus miles*. The site supports more than 1% of the national population of Red-kneed Dotterel, Wood Sandpiper *Tringa glareola*, Greenshank *T. nebularia*, Marsh Sandpiper *T. stagnatilis*, Little Curlew *Numenius minutus*, Australian Pratincole and Oriental Pratincole. The site is also regionally significant for Green Pygmy Goose *Nettapus pulchellus*, Comb-crested Jacana *Irediparra gallinacea*, and Yellow Chat *Ephthianura crocea*.

MULTIPLE USE ON THE LOWER MARY RIVER WETLANDS

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ABSTRACT

The Mary River wetlands are listed in the Directory of Important Wetlands in Australia. The wetlands are characterised by abundant wildlife, including numerous waterbirds and a healthy population of estuarine crocodiles. The second largest area of Melaleuca swamp in the Northern Territory occurs on these wetlands.

The Northern Territory Government has adopted a policy of multiple use for the management of the Mary River wetlands. The existing uses range from flora and fauna conservation, tourism, recreation, pastoralism and horticulture. There are a number of issues that exist between these varied uses that need addressing.

To ensure the success of multiple use of the wetlands, requires the identification of significant sites for conservation, tourism, recreation and industry. Through the integration of development and conservation objectives, economic growth can be achieved at a known and acceptable environmental cost.

The solution to multiple use over an area such as the Mary River wetlands lies in comprehensive catchment management. Management in this sense is a continual process of planning, implementation, monitoring, evaluation and adjustment of management. The key features of this framework are monitoring and re-evaluation. It is through this feedback loop that the success of management can be assured.

Keywords: wildlife, waterbirds, estuarine crocodiles, melaleuca swamp, multiple use, flora and fauna conservation, tourism, economic growth.

1 Introduction

The Mary River is located 100 km east of Darwin and is a large river that drains northwards into the van Diemen Gulf. It has a total catchment area of 7700 km^2 with a wetlands area of approximately 1300 km^2. The lower Mary River wetlands are defined by the area north of the Arnhem Highway and include also the two small adjacent catchments, Swim Creek and Love Creek.

The Mary River is fairly unique in that its drainage channel has not always entered the sea through a discrete channel. Up until the 1940's the Mary River drained through a series of discontinuous billabongs, that only flowed during the wet season. Since the 1940s, this has changed due to salt water intrusion which has caused headword extension of Sampan and Tommycut Creeks to as far as Shady Camp.

The Northern Territory Government has adopted a policy of multiple use for the management of the NT wetlands. The aim of a multiple use policy is to maintain biological diversity and other natural resources, plus promote ecologically sustainable development. Successful multiple use of the NT wetlands (including the Mary River), requires the identification of significant sites for conservation, tourism, recreation and industry.

This paper discusses the many conflicting issues that exist between the various uses, details the present management and research activities, plus the scope for future research.

2 Conservation values

The Mary River wetlands are listed in the Directory of Important Wetlands in Australia. These wetlands provide a breeding area, habitat and refuge for wildlife populations, especially water birds and estuarine crocodiles. They assume greater importance in the face of rapidly shrinking habitats in Australia and the rest of the world.

Flora values

The vegetation of the wetlands are predominantly grasslands or Melaleuca swamps, with some significant areas of rain forest on the fringing uplands.

- Monsoon forest at Mt Bundy and the Mary River crossing area contain endemic and rare species, which are of international significance.
- The floodplains have important flora values; ie Mary River Conservation Reserve has the seconded largest area of Melaleuca forest in the Northern Territory.
- Much still remains to be learnt about the nature and dynamics of the wetland vegetation.

Fauna values

The wetlands are characterised by abundant wildlife, with numerous waterbirds and a healthy population of estuarine crocodiles (*Crocodylus porosus*). These are of considerable interest to visitors and depend for their conservation on the maintenance of habitat and biodiversity.

- Major Magpie Goose (*Anseranas semipalmata*) breeding area on Opium Creek and Marrakai Station which provide recruitment for populations over the wetlands.
- Largest egret (*Egretta alba*) rookery know in the Northern Territory, on a coastal area at Chambers Bay. Four egret species, as well as darters and cormorants regularly breed there.
- On the Wildman Reserve there is a significant colony of nesting white breasted sea eagles (*Haluectus leucogaster*).
- Coastal areas provide for significant wet season breeding of waterbirds, especially radjah shelduck (*Tadorna radjah*).
- Along the Mary and McKinlay Rivers upstream of the Arnhem Highway are significant populations of freshwater crocodiles (*Crocodylus johnstoni*) and a major brolga (*Grus rubicundus*) breeding area.

3 Current landuses

The Northern Territory Government has adopted a policy of multiple use for the management of the Mary River wetlands. The following are a list of the present uses.

Pastoralism

Just over 70 percent of the wetlands are managed for pastoral use. This includes the pastoral leases of Woolner, Marrakai and Annaburroo Stations, and the crown lease buffalo blocks of Carmor Plains, Swim Creek Plains, Opium Creek and Melaleuca Stations.

Conservation

The Conservation Commission of the Northern Territory (CCNT) manages 8 reserves (Mary River Conservation Reserve, Point Stuart Coastal Reserve, Stuarts Tree Historical Reserve, Swim Creek Reserve, Alligator Lagoon Reserve, Shady Camp Reserve, Wildman River Reserve, Mary River Crossing Reserve), with a total area of 86 045 ha. There is approximately 36 000 ha of wetlands. Wildlife conservation, research, education courses and wildlife utilisation are some of the activities undertaken on these reserves.

Tourism

Within the area concerned, there are a number of sites utilised by tourism. there are 3 tourist accommodation enterprises, 5 CCNT camping grounds, boat tours, dinghy hire operation and general eco-tourism.

Recreation

Most of the waterways are heavily utilised for amateur fishing.

Fishing

On the Mary River.

Horticulture

A cashew nut plantation is being trialed east of the Wildman Reserve.

Mining

A number of mining operations occur in the upper catchment, including sand mining and gold mining. These operations, though not in the area of concern, potentially can have a significant impact through poor water quality.

Defence

The Defence Department uses a number of areas for training purposes.

4 Management groups

The Lower Mary River Landcare Group was formed in 1989. Members represent the range of uses in the catchment. At the request of the landcare group, a Government Departmental working group (Lower Mary River Technical Working Group) was formed to co-ordinate all Government activities on the Lower Mary. There is frequent contact between appropriate Government Departments and landholders, with a number of integrated catchment workshops being held.

5 Management issues

The management issues to be faced in achieving multiple use were identified by the Mary River Technical Working Group. The following are descriptions of the major issues and current management and research.

Saline intrusion

Over the last 50 years, approximately 17 000 ha of grasslands and Melaleuca swamp on the Lower Mary River plains have been affected by saline intrusion. In addition a further 50 000 ha are immediately threatened if saline intrusion is not controlled. Saline intrusion is the great simplification of the system through the conversion of most of the area of deep backswamps from freshwater to marine systems. Not only will a diversity of wildlife habitats be lost in exchange for a few that are already abundant throughout the region, but it will also jeopardise the future of pastoral operations.

Since 1989, the CCNT and affected landholders have been activity involved in managing saltwater intrusion. This has included a barrage construction program, a geomorphological study (Geomorphology of the Lower Mary River Plains, Northern Territory; Woodroffe & Mulrennan 1993), a monitoring program and a collaborative study with the Power and Water Authority (PAWA), to model the hydrodynamics of the tidal system and possible long term options.

The barrage construction program has been successful in halting any further intrusion in the short term and has effectively rehabilitated approximately 2000 ha of previously salt affected plains.

PAWA studies suggest the partial dampening of the mouth of Tommycut and Sampan Creek offer the most appropriate solution. This would reduce tidal amplitude and the ability of tides to invade new areas, while still allowing unrestricted fish access.

The fishing industry is concerned that the barrages may impede the movement of barramundi, particularly in the juvenile stage during their first upstream migration. The Department of Primary Industry and Fisheries (DPI&F) is undertaking research in this area. To date there is no evidence to show that these works have a detrimental effect on fish population or their migratory pattern.

Weeds

Noxious weeds that occur are mimosa (*Mimosa pigra*), spinyhead sida (*Sida acuta*), flannel weed (*Sida cordifolia*), hyptis (*Hyptis suaveolens*), sicklepod (*Senna obtusifolia*), coffee senna (*Senna occidentalis*), mission grass (*Pennisetum polystachion*) and water lettuce (*Pistia stratiotes*). Weeds are a major issue for the viability of pastoralism, conservation and tourism.

The main problematic weed is mimosa, which infests approximately 4000 ha. The DPI&F, CCNT and affected landholders have formed a mimosa control group, which coordinates control activities over the wetlands.

The potential introduction of aquatic weeds, salvina (*Salvinia molesta*) and water hyacinth (*Eichlorinia crassipe*) is a major concern, especially as the wetlands become more open to public access.

There is considerable debate about effect on the environment by introduced pasture species. The two species of concern are para grass (*Brachiaria mutica*) and gamba grass (*Andropogan gayanus cv Kent*).

Wildfire

Wildfires is an issue that effect all uses, with at least one major fire occurring each year.

A fire management plan is being developed for the Point Stuart District. The plan will have to account for the range of fire management practices for the different uses. This will range from fire exclusion to active burning.

Habitat degradation

This includes both the loss of habitat through land development and the degradation of habitats through poor grazing management. A properly managed extensive grazing system has little impact on conservation values, as it will retain areas lightly grazed or not grazed at all that will sustain a diversity of habitats.

Where uniform heavy grazing pressure occurs, the area is predisposed to erosion, hydrological changes and weed infestation. Many species cannot persist in such a system.

Ponded pastures

Ponded pastures presently do not exist on the Mary River wetlands, other than a small area on Opium Creek Station. But as pastoralism develops and the cost/benefits become more favourable, it would be expected that they will become an issue, as in the case in Queensland.

A wetlands capacity to support a diverse range of wildlife depends on the diversity of wetland habitats. The concern with ponded pastures is if their use become widespread, diversity of habitats will be reduced. There will be a disproportion of deeply flooded sites compared to shallower plant communities that fringe these areas.

Land competition

Significant competition exists for a limited land resource between the various landuses (pastoralism, horticulture and conservation). A particular problem is the imbalance of floodplains to uplands on some pastoral properties, which leads to overgrazing of the uplands if the floodplains are fully utilised.

There has been a call for a Landuse Study of the Lower Mary River. It is felt instead of this study, it would be more appropriate to do an Integrated Catchment Management Plan that can address all the major issues.

Land clearing

There has been minimal clearing to date, which has only occurred on the uplands. Approximately 3000 ha has been cleared for improved pastures and infrastructure development. The concern is, if extensive clearing occurs there will be a loss of habitats, and the potential for accelerated erosion and weed infestation. The Landcare Group and CCNT are developing a Code of Practice for Clearing on the Lower Mary River.

Water quality

Deteriorating surface water quality is a concern to the biological integrity of the wetland system. Mining, horticultural, pastoral and tourism can all potentially impact on water quality by increasing nutrient levels, sediment and turbidity levels, and the introduction of toxic agents.

Feral and endemic pests

The expected expansion of horticulture in the region will lead to a conflict with wildlife. Magpie geese, red-winged parrots, red-collared lorikeets and sulphur-crested cockatoos in particular can all inflict heavy crop losses. Feral pigs are a continual problem, and cause significant damage to the environment.

6 Current management/research

The following is a list of the current major management/research activities on the Lower Mary River.

- Magpie goose research and management, included egg harvesting (CCNT)
- Aerial and ground surveys of waterbirds (CCNT)
- Estuarine crocodile egg harvesting (CCNT)
- Vegetation surveys of the wetlands (CCNT)
- Pasture research (DPI&F)

- Property management planning (Landholders, DPI&F, CCNT)
- Weed control and research (DPI&F, CCNT, Landcare Group)
- Fire management (Landholders, CCNT)
- Tourist and National Park concept plans (CCNT)
- Tidal hydrodynamic modelling (PAWA, CCNT)
- Water quality studies (PAWA)
- Salt water intrusion rehabilitation program (CCNT, Landholders)

7 Achieving successful multiple use

This paper has highlighted the major issues that have arisen or will arise during further development of the Lower Mary River. The solution to multiple use lies in management, where all of these issues of concern are raised and joint management proposals are adopted. Management in this sense is a continual process of planning, implementation, monitoring, evaluation and adjustment of management. The two important steps are monitoring and evaluation, which are the feedback loop which should ensure the continual success of multiple use.

Most management decisions cannot be postponed to allow research to be completed. There has to be an integration of research activities within the management action.

A forum of all stakeholders need to be established to identify longterm goals, develop priorities and management strategies.

8 Areas of further management/research

- Effects of fire on wetland ecology.
- Effects of grazing intensity on wetland ecology.
- Flora and fauna research on species poorly studied.
- Acid sulphate soils
- Integrated catchment plan for the Lower Mary River.
- Produce/implement land management strategies for weeds, fire, feral animals, wildlife utilisation etc.

9 References

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WETLANDS OF THE LOWER BURDEKIN REGION, NORTH QUEENSLAND

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ABSTRACT

The freshwater wetlands of the lower Burdekin reflect the nature of the wet-dry tropics. The aseasonal climate often results in the rapid transformation of wetlands and their associated biota. Limnology and classification of tropical wetlands is dependent upon repeated sampling and a greater consideration of abiotic attributes. Management requires an understanding of these biological cycles to develop integrated and responsive measures to mitigate development pressures. Traditional land uses coupled with the development of the Burdekin River Irrigation Area has resulted in a variety of impacts on the wetlands. Changes in wetland water quality and inundation regime, weed invasion, grazing pressure and infrastructure placement have all contributed to the deterioration of wetland integrity. Research and development of artificial wetland technology has the potential to improve the values and functions of degraded wetlands.

Keywords: freshwater wetlands, north Queensland, limnology, wetland classification, management requirements

1 Introduction

The Burdekin River has a catchment of about 130 000 km^2 and its delta and floodplain are the largest in the tropical north-east of Australia. The Burdekin River has recorded the greatest instantaneous peak discharge of any river in Australia and has a mean annual discharge of nine million megalitres (Burdekin Project Assessment Committee 1978). The floodplain has an area of about 900 km^2 (Hopley 1970) and is bordered by the Burdekin delta to the east, the Haughton River to the west, the Leichardt range to the south, and the estuarine and littoral zone to the north. Barratta Creek drains the middle of the floodplain and, together with numerous lagoons, billabongs and swamps, is part of an intricate mosaic of rich and diverse wetlands. The fertile alluvial lands of the delta and floodplain have supported the development of one of Australia's most intensive agricultural areas, including one of Australia's main sugar growing regions.

Water management has been a major aspect of agriculture on the Burdekin River delta and floodplain. Traditionally, the area was farmed for sugarcane and horticulture using surface water from channels and lagoons. These supplies were eventually supplemented by pumping from shallow unconfined aquifers, the use of bores to tap into the groundwater soon followed, an aquifer recharge scheme was developed, and water was pumped from the Burdekin River and delivered to the delta along two small streams (Plantation and Sheepstation Creeks). The construction of the Burdekin Falls dam and infrastructure, and the resumption and development of farming lands by the (then) Queensland Water Resources Commission led to rapid expansion of the sugar cane growing area, with the first of the new farms being auctioned in 1988. Land is currently being developed for further expansion of the Burdekin River Irrigation Area (BRIA).

The wetlands of the lower Burdekin have proven to be invaluable to the communities which settled in the region, whether the water was used for irrigation, stock watering or human consumption. These wetlands are also an important waterfowl habitat (Blackman & Locke 1985) and contribute to important commercial and recreational freshwater and estuarine fisheries, especially for barramundi. The lower reaches of this region are included in Cape Bowling Green National Park, an area designated to be listed under the Ramsar Convention on Wetlands of International Importance.

2 Wetland classification/spatial variation

The high diversity of wetlands in Australia is a reflection of our distinct climate, topography and water regimes. The increased awareness of wetland functions and values in Australia has resulted in surveys and classifications designed to protect wetlands on a national or state-wide basis. National or multi-state wetland surveys and classifications have been conducted usually close to centres of population, and using a variety of techniques (see Pressey & Adam 1992). In Queensland, Stanton (1975) was the first to assess the wetlands of the entire state. Wetlands were identified by vegetation assemblage and classified based on geomorphology, rainfall, salinity and water regime. Arthington and Hegerl (1988) used vegetation and floristics to list wetland types and recently Blackman et al (1992) have adapted the United States approach of Cowardin et al (1979) for field assessment and classification of Queensland's wetlands. The assortment of methods used in inventory and classification in Australia has often resulted in incompatible results or those which are only appropriate for particular regions. Barson and Williams (1991) have stressed that factors used in determining a classification should form part of a 'minimum data set'. This core data set should comprise primary attributes - ie direct measurements or observations. However, the application of these primary attributes to an inventory and classification project is often complex because of inherent difficulties in wetland definition and delineation in Australia.

This survey and classification of wetlands in the lower Burdekin region of north Queensland uses a developed primary data set to construct a numerical classification and also employs a traditional hierarchical classification method (Cowardin et al 1979). The Ramsar definition of what constitutes a 'wetland' was adopted.

2.1 Methods

Over 450 wetlands (perennial or temporary water bodies) were identified from topographic maps. Ninety-four of these sites were sampled in 1991, and all wetlands were classified according to the Cowardin et al (1979) scheme. Forty-one representative sites were then selected as a subset for further seasonal sampling. The second field survey was intended as a 'post-wet season' trip, but was delayed until May 1992 because of the poor wet season. The lack of a significant rain period resulted in wetlands at this time being drier than the previous sampling survey and the field-work was concluded by June 1992. The third sampling trip during September 1992 was a 'pre-wet season' survey when the wetlands were at their driest. The final trip was conducted during March and April of 1993 as a 'post-wet season' survey; however, a second failed wet season only resulted in the 'greening up' of some wetlands. Sampling involved recording: morphology, water quality, aquatic macrophytes, riparian vegetation, phytoplankton, zooplankton, water birds and amphibians. Complementary projects examined aquatic macroinvertebrates and fish distributions in a subset of the wetlands and also terrestrial/riparian vegetation and fauna of the BRIA. This paper presents only some of the research conducted as part of the wetlands study.

2.2 Results and discussion

Using the Cowardin et al (1979) hierarchial classification, the 94 sites were summarised as follows: palustrine, 77 sites; riverine, 11 sites; lacustrine, 5 sites; estuarine, 1 site. Palustrine wetlands clearly dominated the floodplain. This included wetlands which are periodically affected by stream flows and overflows. The 41 sites that were seasonally sampled included 32 palustrine, seven riverine and two lacustrine sites.

Study sites

Of the 468 discrete wetland sites identified from 1983 topographic maps, 20% had been drained and filled for sugar cane growing by the 1991 wetland survey. The large ephemeral wetlands have been most affected with a 50% loss of this habitat in recent years. Elevation broadly divides the floodplain into three zones: lower (5 m), middle (10–15 m) and upper (20–30). The lower zone is characterised by a deep, slow moving river channel (West Barratta Creek) surrounded by numerous shallow wetlands. Within the middle zone, Barratta Creek is a series of long deep pools connected by riffles, reflecting the increase in elevation. Wetlands are dispersed throughout this area but are more defined than in the lower section. The land use around the wetlands includes mainly grazing and agriculture, and no site is pristine. Within the grazed areas there is evidence of selective logging and water bodies are frequently dammed, dug out and/or used as watering holes for livestock. In agricultural areas only a narrow riparian zone remains in most cases; however, banks and littoral zones are not trodden by cattle and the water is usually clearer. Despite these impacts, several high quality wetlands, representing both shallow and deepwater habitats, occur on the floodplain.

Riparian zones

Wetlands of lower East Barratta Creek are mostly dominated by *Livistona* sp. However, this area was extensively transformed prior to the earliest fauna and flora surveys conducted in the 1950's (Perry 1953). To maintain livestock, large areas of the lower floodplain were cleared, burned and dyked to retain freshwater and prevent seawater/tidal intrusion. Continued grazing appears to be restricting forest regrowth in these areas. Remnant patches remain in the adjacent mid and west Barratta Creek floodplain area. The riparian vegetation of the less disturbed Barratta Creek floodway comprises tall floodplain forest dominated by a number of tree species. Rubber vine is a common weed throughout this area.

Aquatic macrophytes

Numerical analyses indicate the data can be separated into two main groups - that which represents grazed, shallow wetlands in which the abundance of *Urochloa mutica* (para grass) was low and *Paspalum*, *Ludwigia* or *Marsilea* were abundant; and that which represented sites where para grass was abundant, and permanent water sites where *Typha* and *Ceratophyllum* were abundant. The abundance of para grass, disturbance and depth of water are important factors in explaining much of the variation in macrophyte communities.

Water quality

The wetlands generally had moderate to high nutrient levels. Principal components analysis failed to separate sites, except on a conductivity axis, with highly saline sites clearly separable from the remaining sites. This result is of particular interest as it suggests that major between-site patterns are not detectable at present. However, it should be noted that these samples cannot represent conditions during rainfall events, nor do they indicate the amount of material stored in sediments and biota. Analyses of these components of the system may well indicate between-site differences and may need to be considered in future work.

Phytoplankton

The phytoplankton species identified in the wetlands of the BRIA are similar to those which were found in the other studies of the region. This result is not unexpected as there is a paucity of endemic tropical species (Kalff & Watson 1986) and most of the other studies have been conducted in similar climatic zones. Finlayson et al (1984) identified 17 genera of phytoplankton near Mt. Isa, of which 65% were recorded in the BRIA wetlands. Similar species were also recorded by Bowling (1988) in south-east Queensland, with more than 52% of the 29 phytoplankton genera recorded in twenty-six sites also occurring in the BRIA wetlands. The Chlorophyta (green algae) comprised almost 60% of the genera identified in the BRIA wetlands, and this domination of the species diversity is consistent with the reported composition of tropical waters (Kalff & Watson 1986). Many of the species identified were common to different wetland types (eg *Trachelomonas*, *Selenastrum*, *Cosmarium*) or found in similar sites but of varying trophic status. This agrees with Kalff and Watson (1986) who stated that 'the presence or relative abundance of species may be less a function of how well particular species are adapted to an environment than their ability to do less poorly at a particular time than other competitors'.

3 General discussion

3.1 Development and wetlands

The commitment to development of the Burdekin River floodplain provides a challenge to the Queensland Department of Primary Industries to put into practice their adopted goal of ecologically sustainable development (ESD). Careful management can be achieved by taking the precautionary approach, especially in relation to: the width of riparian zones; the tenure, design and area of remnant habitat reserves and corridors; the management of tailwater volume; the impact of progressive decline in water quality; and the invasion potential of exotic species.

3.2 Algal blooms

The full extent to which farming practices affect the likelihood and severity of algal blooms remains unclear, but there is evidence to implicate agriculture. Certain environmental conditions can favour the formation of a bloom. These include high nutrients, high light penetration, low turbidity, calm water conditions, long periods of stable weather and high water temperatures (Queensland Water Resources Commission 1992). The dry and warm winters in north Queensland provide excellent conditions for blooms. The removal of phytoplankton predators, such as zooplankton, by chemical contamination (eg pesticides) of sites can also facilitate these bloom conditions. Therefore, the possibility of significant algal occurrences in the waterways of the BRIA is high.

3.3 Riparian zones

The current threats facing the riparian zones within the Burdekin floodplain include:

- Exotic weed invasions, eg rubber vine (*Cryptostegia grandiflora*) which smothers natural vegetation and is the most significant weed in the state in terms of destruction of riparian vegetation and habitat loss (McFayden & Harvey 1990).
- Introduced pasture species such as *Hymenachne amplexicaulis* and para grass (*Urochloa mutica*) which smother banks and inhibit natural recruitment of riparian species.

- Insect-related dieback of river she-oaks (*Casuarina cunninghamii*) and *Eucalyptus* spp., due to extensive tree clearing and associated stream salinity (Sattler 1993).
- River 'improvement' schemes which in the past have straightened channels and removed vegetation and snags, often leading to serious bank erosion and subsequent loss of riparian zones; this is most evident in the older irrigation areas in the delta and also along Sheepstation and Plantation Creek.
- Trampling and grazing by stock which reduces vegetation regrowth, increases spread of weeds and causes bank erosion.
- Permanent inundation and higher base flows which have the potential to drown trees in the riparian zone.

3.4 Grazing management

Shallow seasonal wetlands in the Burdekin region appear particularly prone to damage by cattle. Intermittent swamps were often heavily grazed during the dry season, severely damaging the aquatic vegetation (especially emergent plants). The fringing aquatic vegetation of perennial lagoons is also selectively grazed by cattle. In combination with the attraction of available water, peripheral wetland vegetation attracts continual grazing pressure for much of the year. Planting of para grass in wetland areas has exacerbated the problem. The presence of cattle within wetlands also causes severe disturbance to sediments, disrupting normal plant and animal populations and impacting severely on water quality. The foot imprints on the wetland margins increase available breeding sites for mosquitoes, especially *Aedes* spp. (Hearnden pers comm). The wallowing of cattle results in the deposition of faeces and urine into the water, causing microbial contamination and elevated nutrient levels which may cause eutrophication, particularly during extended dry seasons (Butler & Faithful 1991).

3.5 Irrigation infrastructure and wetlands

Appropriate placement of irrigation scheme infrastructure is crucial to the long-term viability of the remaining wetlands. Levee banks and drains can result in major changes to the water regime of wetlands. Green Swamp has become dry because of irrigation drainage being placed along the length of the wetland, and the values and functions of this large seasonal wetland have been lost. The placement of levee banks perpendicular to the flow in Red Lily Lagoon has resulted in a large and deep water storage area which has facilitated the spread of weeds, choking the lagoon and eliminating native species. Conversely, the development of the Selkirk section has highlighted the potential for ecologically sensitive placement of infrastructure: habitat degradation from inputs of tailwater was averted by drains which bypass the ephemeral wetland.

3.6 Environmental flows

Water management schemes at all levels affect natural flows in watercourses. For example, flows in the lower Burdekin River are controlled by the Burdekin Dam such that minor floods do not occur but continued flow occurs in the dry season as a result of controlled releases. The impacts of such controls have been well described for non-tropical systems, but not for streams in the tropics. However, the need for floods for flushing of vegetation and sediment, and to stimulate migrations and spawning, and the dependence by some of the biota on the water courses drying out, is well known. Therefore, any change in natural flow regimes is likely to cause changes in the biota, often with loss of some species, but often with replacement by others. The streams of the Burdekin floodplain normally cease to flow in the dry season, and contract to a series of pools, or go completely dry. There is an opportunistic fauna associated with these conditions, including those species that rapidly invade when the stream begins to flow and those species which invade as the stream dries. Streams now receiving tailwaters are not prevented from receiving wet season spates but they are prevented from drying. The result is a permanent fauna, with no opportunity for colonisation by temporary components.

Continuous flows may affect the system in other ways. Firstly, waterlogging of stream banks is likely to cause dieback of riparian vegetation, with severe consequences (eg bank erosion and sedimentation, increased light levels and weed growth, reduction of habitat for semi-aquatic and terrestrial species). Secondly, the sediment dynamics are likely to be changed, causing build up of silt, or erosion, depending on the circumstances, with consequent habitat changes. Such changes are evident in the streams of the floodplain. The effects can be reduced by careful water management, especially of tailwaters, and by careful design of drains largely to bypass natural water courses, such that a good proportion of water courses remain unimpacted.

3.7 Aquatic weeds

Invasive aquatic species such as water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*) and para grass (*Urochloa mutica*) dominate many wetlands in the region, with the floating species often covering entire water bodies. Exotic pasture species (eg para grass) have also become widespread weed problems. Aquatic weeds can reduce the mean velocity and conveyance capacity of channels by up to 50% in some cases. Tropical climates allow vigorous growth for much of the year, requiring maintenance to be carried out year round. Large stands of emergent weeds reduce water flows causing sediment to be deposited into the weed bed. Siltation is of particular concern in Pelican and Barratta Creeks where the more stable flows have facilitated the establishment of *Typha domingensis* in the creek bed. Dense growth of this species will obstruct flow, enhance siltation and significantly change the character of the creek and therefore its biota.

3.8 Artificial wetlands

The use of artificial wetlands to 'filter' contaminants from agricultural drainage is being assessed in the lower Burdekin. Trial artificial wetlands have been developed and are currently being researched by the Australian Centre for Tropical Freshwater Research and the Department of Primary Industries. The selection and use of native aquatic macrophytes within drainage systems may improve drains as habitat and also the quality of wastewaters. Experimental drains have been designed on the basis of retention basins with attached surface floating macrophytes (*Nymphaea gigantea*) and trenches with emergent species (*Schoenoplectus validus* and *Phragmites australis*). Seed viability studies are also underway to determine the risk of spread of these species into natural waterways.

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