MOUND SPRINGS MANAGEMENT PLANNING

Management Issues, Strategies and Prescriptions for Mound Springs in Far North South Australia

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FOREWORD

Australia's Great Artesian Basin is associated with hundreds of natural springs where Basin water rises to the land surface through natural cracks and fissures in the geological formation. These are known as mound springs.

As virtual oases in the desert, mound springs are of national significance because of their natural flora and fauna, their very close links with Aboriginal culture and their association with early European exploration and development in the 1800's.

Although many mound springs were fenced off by early pastoralists, the overall impact of introduced stock (and, to some extent, feral animals) on the mound springs has been highly significant. During the 1970's and 1980's efforts were initiated by the South Australian Government and others to document the features of the springs and to protect at least the more significant of them.

These efforts included a fencing program undertaken by the then Department of Environment and Planning. Ten priority springs were fenced during the period 1986 to 1988.

Monitoring of the fenced springs since that time has shown a vigorous response by the native vegetation. At some sites, however, one or two species (eg reeds, *Phragmites*, and bulrushes, *Typha*) have become predominant to the apparent exclusion of other plant species. This has raised questions as to whether management actions other than simply fencing should be considered at some springs to promote a higher level of biodiversity.

At the same time it has long been obvious that other, as yet unprotected, springs warrant further consideration. Many of these are of high conservation priority but have been given only limited consideration in terms of management programs which could help to protect their significant features.

In 1997/98, the SA Department for Environment and Heritage initiated a project to review the management of the mound springs fenced during the 1980's and to develop an overall strategy or framework for conservation and management of unprotected springs. A grant of $30 000 was provided through the Natural Heritage Trust and consultants Fatchen Environmental were engaged to undertake the project.

This report is the result of that project. It provides a comprehensive overview of issues and management strategies, although it must be noted that opinions provided in the report are not necessarily those of the Department for Environment and Heritage.

Department for Environment and Heritage
July 2000

1. INTRODUCTION

1.1 Background

Mound springs along the southwestern margins of the Great Artesian Basin (GAB) in South Australia are widely recognised as being of both State and national significance for their biological values, their significance to Aboriginal communities, and their links to and influence on early European settlement and development.

Moves toward their conservation commenced in the 1970s. Initially, moves were aimed at protection of springs, and their surrounding landscapes, primarily from perceived impacts of domestic stock. The large and extensive Dalhousie Springs and its surrounding gibber landscapes were reserved as Witjira National Park (in 1985).

Prior to the early 1980s, there was little detailed information on the springs, and little interest in their conservation. Harris (1981) reported that the spring biology was poorly known, that springs were degraded by a combination of direct pastoral use and aquifer drawdown from flowing pastoral bores, and that the then emerging Olympic Dam mining venture would create new pressures on the springs.

From the early 1980s, extended and detailed investigations of mound springs were undertaken to fulfil the then environmental impact assessment requirements for the development of the mining, industrial and urban complex associated with the Olympic Dam copper-uranium deposit. The development would require substantial volumes of water from the GAB, and extraction at the rates then proposed clearly had potential for adversely affecting spring flows in a region extending roughly from near Marree to Blanche Cup. Initial surveys and studies in this region, summarised in Kinhill Stearns (1984), were followed by monitoring programs of varying detail. Further studies have accompanied subsequent proposals for expansion of the Olympic Dam operation (Kinhill Engineers 1997).

The precursor of the present Department of Environment, Heritage and Aboriginal Affairs (DEHAA) commenced a study of springs in SA beyond those being examined as part of environmental impact assessment processes in the early 1980s. The subsequent report (Social and Ecological Assessment 1984), covering springs other than Dalhousie, provided the basis for conservation initiatives. Dalhousie Springs was the subject of separate investigations (Zeidler and Ponder 1989). The Department, in collaboration with pastoral interests, fenced ten areas at the following springs to exclude domestic stock:

- Blanche Cup, The Bubbler, Strangways Telegraph Repeater Station (one spring), Big Perry, The Fountain, Twelve Mile, Outside, Tarlton, Old Nilpinna, and Big Cadna-Owie.

More recent fencing for stock exclusion has been the enclosure (by S Kidman & Co) of Strangways Hill; reservation and fencing of the Wabma-Kadarbu Mound Springs Conservation Park which includes Blanche Cup, the Bubbler, and several other vents; and most recently (1996), the fencing of the spring wetland and surrounds at Coward Spring. Monitoring of the fenced groups has been regular, but limited in detail.

Stock were removed from the then Finniss Springs Station in 1984, as part of the Brucellosis and Tuberculosis Eradication Campaign. With one or two minor exceptions, domestic stock were not replaced, and the landholding eventually passed back to the Crown. In effect, the several spring groups within the former station were also protected from stocking. They included the very large spring groups about Hermit Hill, which have been subject to intensive and long-term monitoring as part of Olympic Dam environmental assessment and monitoring.

Monitoring of the DEHAA-fenced springs has shown that stock exclusion can create management issues which require attention. In particular, prolific growth of the reed *Phragmites australis* and the bulrush *Typha domingensis* appears to be limiting other spring flora, potentially affecting spring fauna and, in some cases, altering apparent spring flows. Investigations and monitoring as part of Olympic Dam environmental programs have demonstrated the dynamic nature of the monitored springs, and particularly demonstrated the major changes in spring characteristics and biology which accompany disturbance and protection from disturbance.

1.2 Study brief

The brief for this study is to examine future mound spring management, with special reference to existing and future fencing (stock exclusion) programs.

The brief is limited to springs west of Marree, but excluding the Dalhousie spring group, which is both of a different order as regards its size and flow, and subject to formal National Park management processes.

Management prescriptions for existing fenced springs are required, in view of the observed trend to increased biomass, decreased plant diversity and decreased flow in most currently fenced springs.

Strategic directions are sought for management of other springs, including future fencing. In particular, identification of priorities is sought for currently unfenced springs.

1.3 Limitations

The response to aquifer changes, particularly local or regional drawdown due to mining, industrial or pastoral development, is not included in the management brief. This relates to the larger question of management of the GAB, for which a draft strategic management plan is circulating (GAB Consultative Council 1998). In the following, some questions of aquifer management arise, but solutions are not addressed. For the specific purposes of the brief, the existing (current) aquifer supply *is assumed to be maintained.*

On such a basis, management prescriptions for already fenced springs can be made. There are, however, multiple possibilities, dependent on the actual *objectives* of management. Objectives require the acceptance of at least some degree of specificity. Mound spring management aims to date have largely been general. The emphasis has been on protection from domestic stocking rather than active management for particular purposes or outcomes. Hence, the Dalhousie spring complex is now contained within Witjira National Park and the Blanche spring group within Wabma Kadarbu Mound Springs Conservation Park. The fencing program has provided exclusion of domestic grazing from some springs outside these areas. In relation to industrial development, emphasis has been directed to limitation of impacts on spring water supply. There are important instances where specific and active measures, with defined objectives and intended outcomes have been taken: in particular, direction of tourist visitation and visitor impact limitation in Wabma Kadarbu Mound Springs Conservation Park and in Witjira National Park. Nevertheless, the primary approaches to management remain general, and reliant on passive protection.

Determination of specific objectives depends on strategic priorities. Strategic priorities have to date been based largely on investigations which have not incorporated, and indeed could not be expected to incorporate, more than a very general or very long-term view of spring dynamics. They have also been bedevilled by the potential for multiple interpretation. For example, the DEHAA fencing program largely but not wholly followed an assessment of priorities in Social and Ecological Assessment (1984). SEA's development of priorities, in the absence of any better course to take, was a composite of the significance of biological, social and some geomorphological characteristics and can be challenged. In particular, there were differences in interpretation between their view of significance and that expressed in Kinhill Stearns (1984). Neither is necessarily right or wrong: the differences depend on viewpoints and the weighting given to particular aspects of the springs.

There is clearly a need to develop further the capacity to assess the biological, physical, social and economic values of the springs to allow a much more objective development of strategic priorities than has been possible to date. The present report has only been able to indicate reasonable directions for doing so.

1.4 Report outline

Information on the springs within the subject area is briefly reviewed in the following section, with particular emphasis on aspects directly relevant to the present brief. The physical and biological variation within the mound spring arc is emphasised, as the variation does not fit well with non-varying management approaches. The review is not intensive, since there are now several cogent summaries of the spring information available (eg Boyd 1990). Much of the most recent research on biological and physical aspects of mound springs was addressed at a workshop in Adelaide in November 1998 (Niejalke 1998): part of the proceedings, including a largely complete bibliography, is provided in Appendix N.

The particular issue of reed growth and its consequences, which has become obvious in the fenced springs, is a function of the ecological dynamics of springs. Most of our understanding of the dynamics is derived from the vegetation studies undertaken as part of the Olympic Dam environmental assessments and monitoring: information on spring fauna dynamics is still only at an early stage. The conceptual and predictive ecological models are vital for understanding the inter-relationships between spring flow, vegetation structure and diversity, availability of water at the surface, and disturbance (including stocking). Only part of the information has been widely published, hence the models and their basis are discussed at some length in Section 3, with particular reference to the specific interaction between stock exclusion and plant growth.

The purposes for which springs might be managed are queried in Section 4, with emphasis on the biology. Models and monitoring both demonstrate that biological processes in the springs can be readily manipulated for a multiple of outcomes. Which outcome is actually sought requires an active choice: there are often sound reasons, from different viewpoints, for desiring outcomes which are mutually exclusive. The *de facto* biological objective of protection to date, as defined by outcomes, has been the maximisation of plant biomass and its consequences.

Section 5 deals with questions of spring conservation strategy. A shift in management attitudes is necessary, from an emphasis on protection *per se* to an emphasis on intended and desired outcomes. This shift requires an acceptance that all desired outcomes cannot be achieved in one place, at one time, by one management approach; that active manipulation may be necessary and must be used to achieve some desired outcomes; and that a greater emphasis on non-renewable (non-biological) spring resources is needed. It requires a reworking of strategy, resolving questions of representativeness, and setting a multiplicity of objectives, none of which can be instantaneously achieved: an interim aim of maximising the diversity of outcomes is proposed as a guide.

Some further strategic directions for future management are outlined in Section 5. There are needs for re-examining and expanding the information base, across both a topic range and a geographic range. Monitoring needs to be improved. Experimentation in manipulating for desired outcomes is necessary. Questions of representation of the variety of springs and allocation of resources (prioritisation) need to be viewed in the light of management for multiple outcomes. There are multiple means for achieving conservation objectives, some institutional and some community-based: opportunistic use of what comes to hand fits with an aim of diversity of outcomes. As always, fully satisfying all needs is unlikely to be economically possible. Nevertheless, the springs present a case where real and demonstrable outcomes in conservation management can be achieved without enormous expenditure.

Vegetation management and other issues specific to the already-fenced springs, and the management prescriptions required by the brief, are summarised in Section 6. Descriptions, monitoring results and interpretation, and the specific rationale for the springs are provided in Appendices, to avoid the submergence of the more general issues within the minutiae of individual springs. Prescriptions vary depending on the characteristics, past activity and surrounding context at each spring. The broad aim remains the maximisation of diversity of outcomes.

2. MOUND SPRINGS IN FAR NORTHERN SOUTH AUSTRALIA - CHARACTERISTICS AND INFLUENCES

2.1 Distribution

Mound springs within the study area extend in an arc along the southwestern margins of the GAB in South Australia (Figure 2.1). They are part of a larger arc on the GAB margins extending from Queensland, through northwestern New South Wales into SA and extending into the Northern Territory. General descriptions of the distribution are readily available (eg Greenslade *et al.* 1985, Kinhill Engineers 1997).

For descriptive purposes, the regional and local distribution of springs is hierarchically classified, into spring complexes, regional aggregations of similar water chemistry, and spring groups, which may range from isolated single springs to a local collection of springs associated with a local fault or fracture system.

2.2 Variability

2.2.1 What constitutes a "spring"?

Each individual outlet or vent, naturally discharging artesian water, is considered to be a spring (following Kinhill Stearns 1984). Artesian springs are generally associated with accumulations of sediment, which form a mound. There is however a very great variation in the extent to which a mound is formed, and a confusion between the mound of sediment and the spring vent or vents on that mound.

The usual presentation of a "typical" mound spring (eg Boyd 1990) is that of Figure 2.2 (A). Unfortunately, this representation, found throughout the mound spring literature, equates the spring to the mound, and this is so for the best-known example, Blanche Cup. A mound however may support multiple vents (Figure 2.2 B). As examples, the Fred East spring group comprises two very large, low mounds: ovals respectively 130m x 30m by 8m high and 60m x 30m by 4m high (Boyd 1990). Each carries several distinct and separated vents. Big Perry is a single mound with multiple vents; Strangways is a collection of spring-built terraces and mounds with multiple vents.

The distinction between mound and spring is vital in relation to spring dynamics, both physical and ecological. Applying the distinction reconciles the observed short-term ecological and geomorphic dynamics, and variation in flows of individual springs (vents) with the very long-term continuation of spring activity indicated by the extent of spring deposits (mounds). On a mound, a spring may become extinct and a new spring appear in rapid sequence, on a timescale of a few years or less. Both may in turn contribute to the continued accretion of the mound. The mound develops on a much longer timescale than the individual springs on it.

Figure 2.1 Mound springs between Marree and Oodnadatta

Modified from Harris (1992)

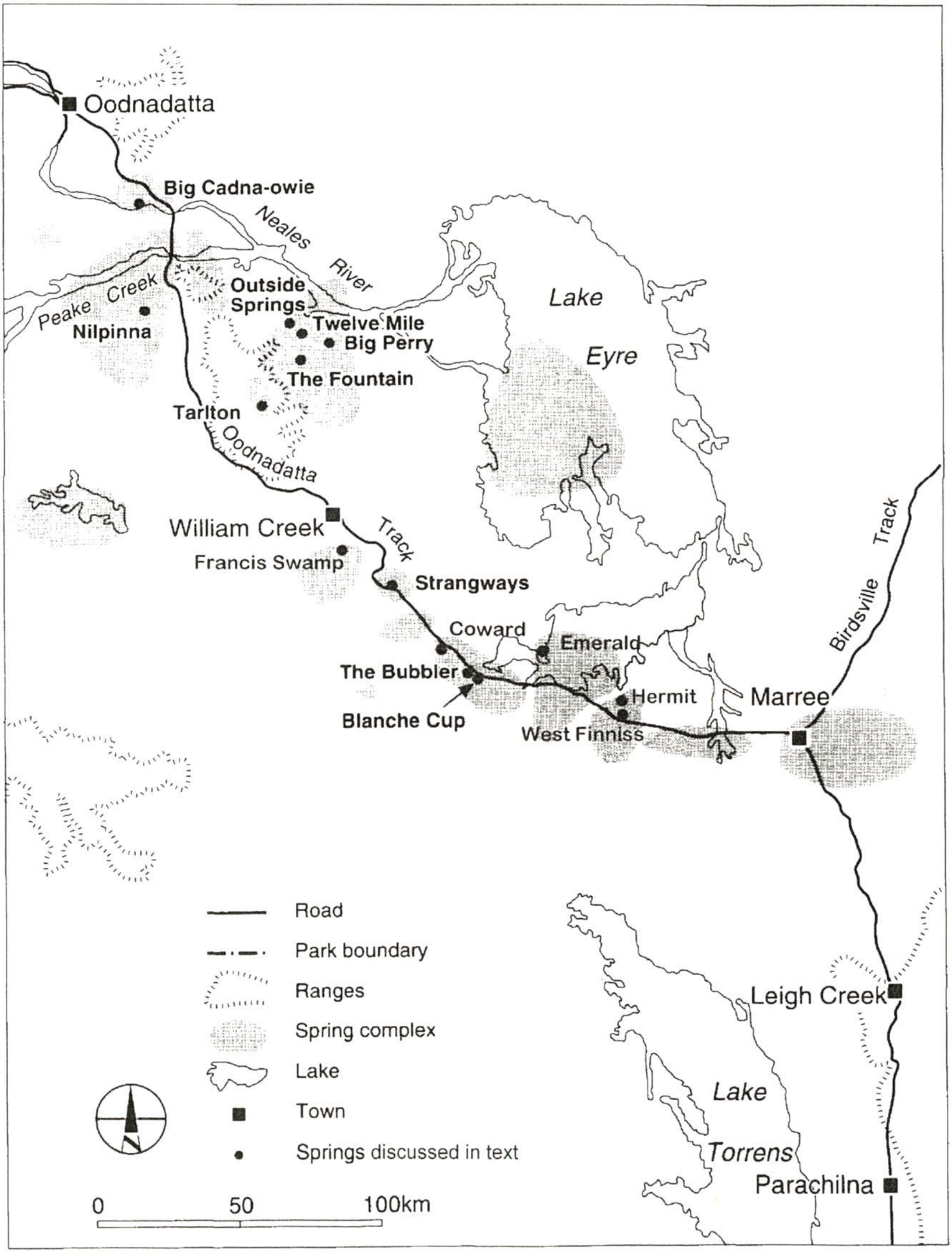
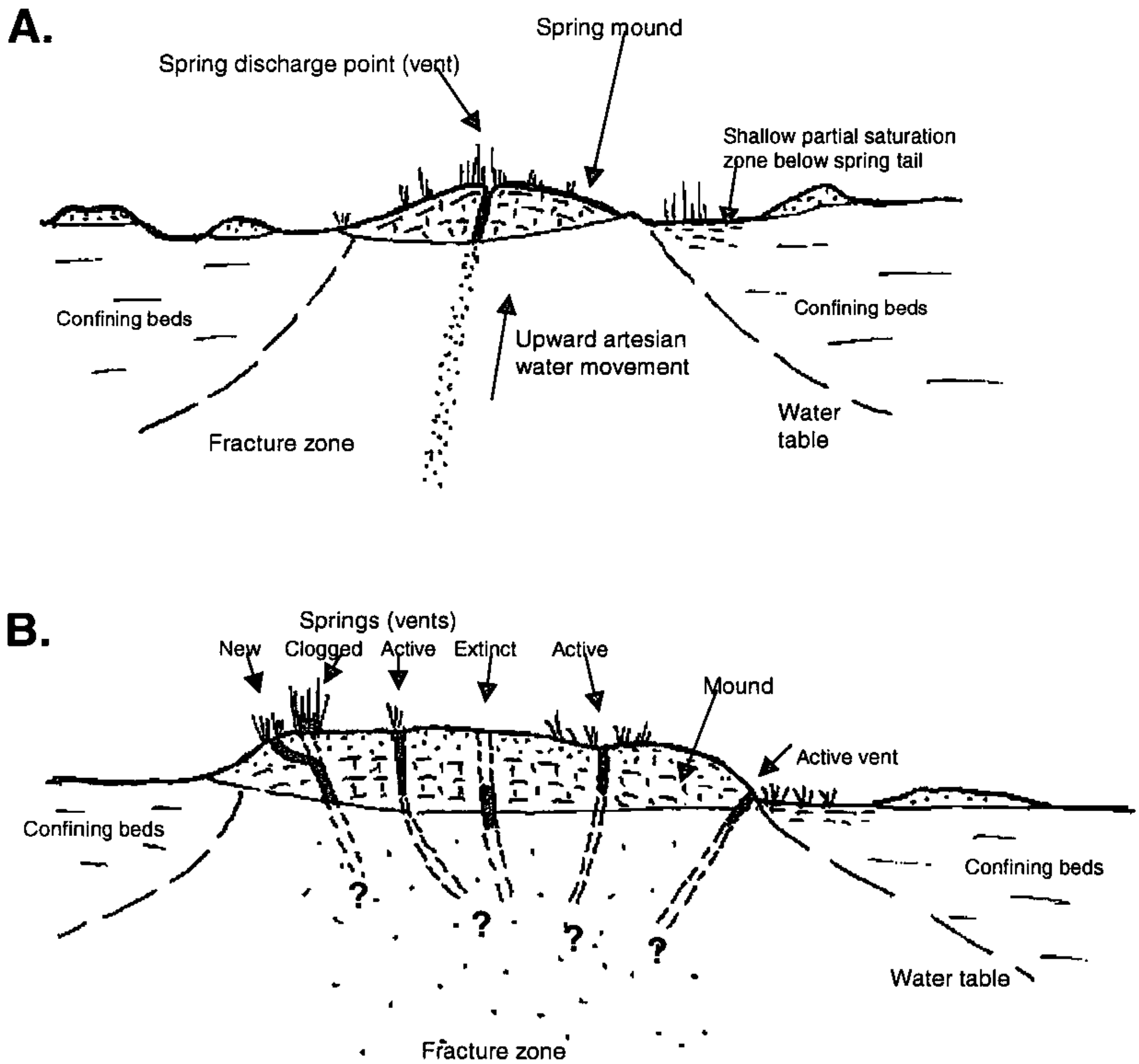


Figure 2.2 Mound spring representations

(A) Usual representation after Thomson and Barnett (1985)

(B) Single mound, multiple springs.

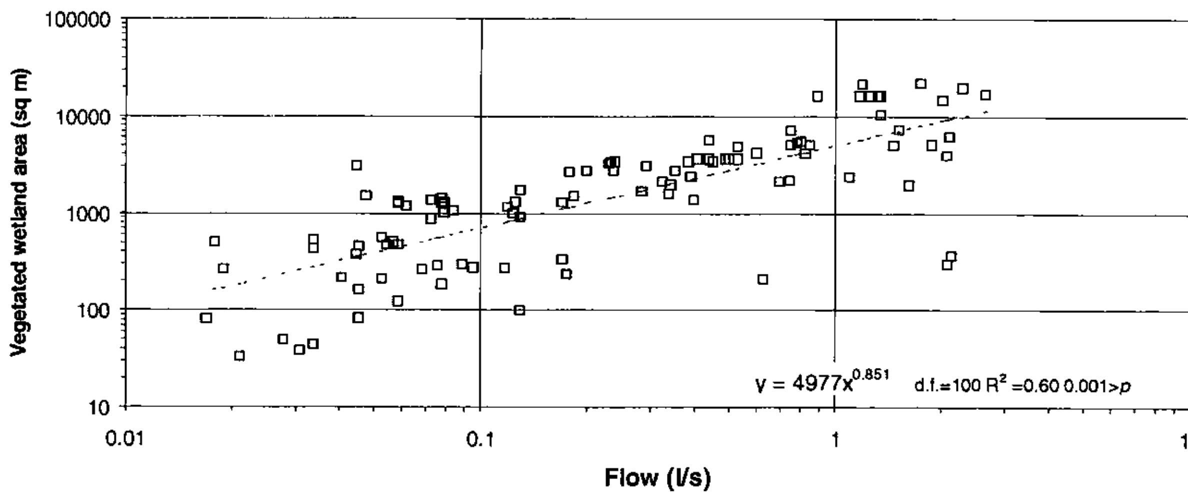


2.2.2 Current spring flows

Spring flows in SA range from minuscule seepages to a maximum flow of some 138 L/s (one spring in Dalhousie Springs - Krieg 1989). In terms of the number of springs recorded to date, most springs in SA have a flow less than 1 L/s. For the region between Blanche Cup and Marree, the maximum recorded flow from large springs is about 3 L/s (WMC monitoring data).

In the same region, more than half the springs monitored have been estimated, based on their vegetated area, to have an apparent flow rate of less than 0.1 L/s (Fatchen and Fatchen 1993). Monitored vegetated area and monitored spring flows in this region correlate closely, though the relationship (Figure 2.3) is not the linear one suggested by Williams and Holmes (1978). It could well be argued that the archetypal mound spring in this region is a small boggy mound of minimal flow.

Figure 2.3 Flow and vegetated wetland area relationships, Hermit Hill area



Sources: Fatchen and Fatchen (1993), flow data from Land Use Consultants (1992)

The finding however can be extended throughout the arc of mound springs, excluding always the large Dalhousie spring group, where some thirty springs account for 90% of the total spring flow in SA (Krieg 1989). Within the Wabma Kadarbu reserve, there are numerous small springs other than the major flowing vents of Blanche Cup, Bubbler and Little Bubbler. In Francis Swamp, most springs are small with little flow evident. In the arc of springs extending north to Freeling Springs, small springs are the more common.

Perhaps inevitably, both past research and past management attention has always focussed on large springs of large flow, rather than on the far more numerous small springs of small flow. This focus is evident in the past spring fencing program, where in most cases fencing was applied to single springs (or single mounds) at the high end of the flow spectrum (Appendices).

2.2.3 Water sources and water chemistry influences

Water sources

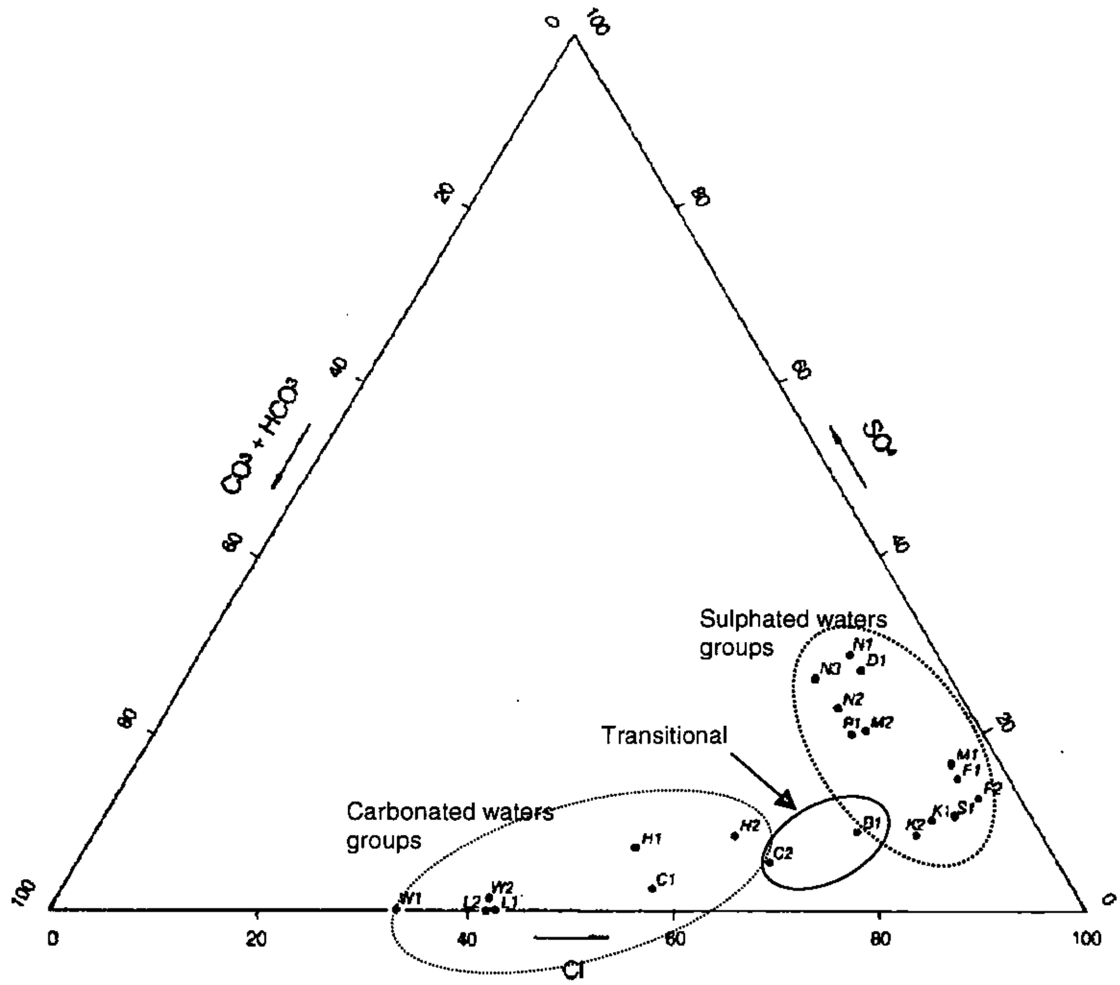
There are two primary water sources supplying the arc of springs along the southwestern margin of the GAB. A summary is provided in Boyd (1990). The water chemistry has a significant influence on mound building, and on spring vegetation.

The major water source comes from the uplands of the eastern margin of the GAB in Queensland. The secondary source is along the western GAB margin in SA. Water deriving from the first is characterised by high carbonate, moderate chloride and low sulphate content ("carbonated waters"), and that from the second by low carbonate, high chloride and moderate sulphate content ("sulphated waters").

There is a general changeover from the eastern to the western source within the study area. From water quality analyses in Kinhill Stearns (1984), we can regard the supply to springs east of the Coward Springs complex as largely carbonated waters, that to the west and northwest as largely sulphated waters, and the Coward Springs complex, including Blanche Cup, as a region of changeover (Figure 2.4).

Figure 2.4 Trilinear plot of ionic composition of bore water for major anions.

Bores between Marree and Oodnadatta: Figure 3.3 of Kinhill Stearns (1984)



Mound building

The extent of mound formation is related to the water source changeover. Springs east of the Coward complex, particularly the extensive groups about Hermit Hill, do not form large mounds. The most common forms do contain spring carbonate deposits, but mounds tend to be low, and usually of accreted windblown (or floodborne) sediment. In the Coward spring complex, tall limestone mounds are common, the best-known being Blanche Cup. West and north of Coward Springs, the clean and regular limestone mounds are replaced by gypseous deposits. Within this rather gross summary, there are multiple variants because of the influence of local differences in water chemistry dependent on local geology.

Many springs do not form mounds. Examples are springs in direct exposures of the aquifer at the surface, such as the series of vents on exposed faults on the lower slopes of Hermit Hill, and the similar exposures at Tarlton. Some "springs" in Lakes Conway and Warrangarranna appear to be simply evaporation sumps in the exposed aquifer, with no flow away from the vent and little accumulation of sediment. Springs in flood courses may be unable to form permanent mounds because of flooding: this has particularly importance in ecological dynamics and is discussed separately.

Influences on spring biota

Water quality strongly influences the vegetation, and in turn, other aspects of the ecology of springs and human perception of their condition. First, the semi-aquatic plant species regarded as typical of mound springs are freshwater species, (Symon 1985; Kinhill Stearns 1984) and are not found in the most saline springs (which often are not regarded as mound springs in any case). Second, the changeover from carbonated to sulphated waters influences the occurrence and abundance of major plant species and some of the relict flora.

In the carbonated waters from Coward Springs east, the reed *Phragmites australis* and the sedge *Cyperus laevigatus* are constant and major, often dominant, constituents of spring vegetation. The sedge *Cyperus gymnocaulos* is present but uncommon. The bulrush *Typha domingensis* is rarely even found on springs, although common in boredrains in the region (Kinhill Stearns 1984 from Fatchen & Associates 1983). This situation partly reverses in the sulphated waters west of Coward Springs. *Phragmites australis* may still be a major constituent, but *Typha domingensis* and *Cyperus gymnocaulos* become common and often dominant constituents of spring vegetation, while *Cyperus laevigatus* becomes a minor component.

The narrow endemic plant *Eriocaulon carsonii* is only found in spring groups receiving the carbonated (eastern) water, with its western limit, and its main population, near Hermit Hill. Occurrences of the relict species *Gahnia trifida, Baumea juncea* and *Juncus kraussii,* however, are found sparsely throughout (Symon 1985).

2.2.4 Influences of topographic location

Currently active springs are generally in topographic "lows" (Boyd 1990). Those set in major watercourses are subject to much more short-term physical variability than springs on plainland. Near Hermit Hill, major floods in 1984 were observed to have altered the spring geography, totally erased some springs, bisected an accreted mound and deposited sediment on others. Near Fred Springs, flooding in 1989 was followed by a brief (2-year) development of flowing springs on the Fred West mound, previously regarded as totally extinct. Such growth-catastrophe-regrowth scenarios, in conjunction with the size and compactness of spring groups appear to play a large part in the biological composition of springs. On present data, the most diverse biological systems are found in compact spring groups, with numerous springs, where individual springs are subject to disturbance (Fatchen and Fatchen in prep.).

2.2.5 Influences of spring group size and compactness

From the intensive Olympic Dam baseline investigations into the spring flora, plant species richness and plant species diversity are both functions of the number of springs in a spring group and apparently the compactness of the spring group (Lange and Fatchen 1990). The high richness and diversity are maintained by the maintenance of opportunities for colonisation, regardless of any competitive differences once the individual species are established. Opportunities may be provided by catastrophic occurrences such as flooding or fire (both of which have now been observed to occur naturally), or by manipulation such as feral or domestic grazing at shifting levels.

The greater the number of springs, the more opportunities there are for maintaining unusual assemblages, but only if the organisms can readily move from opportunity to opportunity. This is a particularly important mechanism where spring flows are low, the usual case for the area monitored as part of the Olympic Dam operations. The low flows do not permit much niche variation in the very small wetlands which they form, a reason for the richness and diversity of the spring vegetation being related to the number of vents rather than the area of wetland (Fatchen and Fatchen 1993). In contrast, springs of very high flow develop extended wetlands, such as those at Old Nilpinna (Appendices), Ockenden or the major springs at Dalhousie. These may contain major temperature and water quality gradients (as in Glover 1989 and other examples in Zeidler and Ponder 1989), with the greater niche variety allowing for higher species richness and diversity without the necessity for multiple colonisation opportunities.

2.2.6 Spring ecological dynamics

Baseline environmental studies also indicated that spring vegetation had to be highly dynamic in an ecological time-frame (ie on the scale of years or less), and that long-term successional processes were not in play (Lange and Fatchen 1990). Subsequent monitoring confirmed the hypotheses (Fatchen and Fatchen 1993). Mechanisms, discussed in more detail in Section 3, are provided through the interaction between vegetation and water supply, disturbance, and local colonisation/extinction activity.

Current evidence indicates that:

- the main control on springs, other than the artesian water supply itself, comes from the dynamics of the vegetation, and
- manipulation of the spring vegetation is likely to be the most appropriate management tool for biological conservation.

2.2.7 Management implications of variation in springs

The preceding indicates springs vary widely in their water quality, water volume and flow, accretion and non-accretion, topographic position, and size and compactness, even before one considers variation which might be imposed by influences such as stock and water extraction.

Springs are not uniform entities. It should then come as no surprise that their ecological dynamics also turn out to be non-uniform.

It also follows that management approaches need to be pluralistic. Appropriate management for a spring with a flow of 0.1 L/s is unlikely to be equivalent to that for a spring with a 10 L/s flow, and totally inappropriate for a spring with a 100 L/s flow. What might well be appropriate in a highly dynamic situation such as a spring group set in a major floodcourse may be totally inappropriate for unpressurised aquifer exposures such as those in Lake Conway. Management needs for a spring with a large carbonate mound may differ from those for a spring with no mound at all. Approaches to management of a large compact group, containing hundreds of springs, are unlikely to be appropriate to a single isolated spring.

The point may seem obvious. Unfortunately, published attitudes to management, conservation and protection of springs are still permeated by the notion of mound springs as uniform entities. Blanche Cup is presented as the archetypal example, and the majority of fenced springs show a familial resemblance: large mounds and high flows. As regards spring management, the dynamics implicit in the interactions between size and compactness of spring groups, disturbance, vegetation dynamics and flows have received little attention until now. There appears to have been a general assumption that protection from stock would, of itself, protect springs and maintain a desired state, without the desired state necessarily being defined, and without full consideration of the processes which determine the desired state.

2.3 Human influences

2.3.1 Aboriginal occupation

Up to early European settlement in the 1850s, springs were a focus of Aboriginal activity. Abundant evidence remains in the form of archaeological material, and in the mythology of tribes occupying the region. Lampert and Hughes (1985), examining the archaeology of the arc of springs in SA, concluded that the sites overall were a regionally important archaeological resource, but also concluded that considerable degradation had resulted from trampling by stock, and from infrastructure construction. Other studies, summarised in Harris (1992), further emphasised the significance of the archaeological resource.

The traditional people of the region were the Kuyani, Arabana, Aranda and Wongkanguru (references in Boyd 1990). While detribalisation over much of the area occurred relatively early (Harris 1985), it does not appear to have been as total as indicated in Boyd (1990). The study area is subject to Native Title claims, some competing.

The detail of how and to what extent Aboriginal people managed the springs is not known. It is likely that fire was used as a management tool. The comment from one initiated Elder was that Aboriginal people burnt vents frequently, possibly annually (Angus Warren, pers. comm. to FJ Badman, 22 May 1993; discussions of C. Woolard with initiated men in the early 1980s). Occasional burning was employed by pastoral operations to maintain the water supply at springs of higher water quality. The last known application of burning was in the late 1980s at Emerald Spring. It is most unlikely that Aboriginal people would not have been aware of this means of management, and it may be that the early pastoral operations may have followed their practice. This does not necessarily mean that Aboriginal people burnt all springs, nor does it indicate the timing of burning or the frequency of burning.

2.3.2 Early and current pastoral use of springs

Pastoral expansion in northern SA utilised the springs as the initial water source. Springs were often fenced to protect the water resource, particularly where springs were isolated (as opposed to multiple springs in a compact group). Individual springs within a group might also be fenced. Remnants of 19th and early 20th Century spring fences and walls persist, but in real terms the percentage of fenced springs may have been smaller than that often suggested (eg in Social and Ecological Assessment 1984). There are some 13-15 actual or apparent remnants of fences or walls protecting individual springs between Marree and Blanche Cup, an area with at least 600 separate springs. A higher proportion of springs east of the Denison Ranges was fenced.

Accordingly, the stock pressures of trampling and grazing on springs generally would have been significant from the start, and not a consequence of the spring fences being let go in the subsequent shift to reliance on bores for water.

In the focus on springs as a water resource, it appears often forgotten that they present a minor grazing resource as well. Particularly in drought, they may be the only local source of green feed. In major concentrations of springs, as in the Finniss Creek and subsidiary courses about Hermit Hill, the forage opportunities may have been as important to early pastoral use as the need in some cases to protect the water source.

In the first half of this century, the sinking of artesian wells in the GAB reduced pressures resulting in a visible decline in flows (Habermehl 1980). Many of the earliest bores were sunk in or next to springs, with the disappearance of the springs as a consequence. There are multiple examples particularly between Marree and Coward Springs: no signs of the original multiple springs remain at the bored Hergott Springs; the extinct spring at Venables, with its stone catch-wall and trough, sits some metres above the early pastoral bore which caused its extinction; and there is no trace of where the spring at Jacobs Spring might have been prior to sinking of the present pastoral bore.

Later bores were sunk near but not in springs, but cones of depression nevertheless reduced spring flows. Hence there is a bare remnant of flow at Welcome Spring (Billa Kalina station), and reductions in springs at Levi and Milne, where the bores are up to 1km away from the springs.

Bore water quality is generally higher for stock purposes, and the flow greater, than from springs near bores. Accordingly, current pastoral reliance for water is placed on the bore, and most 19th Century spring fences have been let go. However, the forage in springs still attracts stock, even though watering preferences favour the bore. Hence, although grazing and physical damage to springs may be reduced to less than that which might occur due to constant stock watering, stock nevertheless still use springs. Their usage is greatest when surrounding pastures are dry, at which time stresses on the wetland margins are also likely to be highest (Section 3).

2.3.3 General effects of water extraction for pastoral and industrial purposes

There has been a well-documented decline in spring flows generally resulting from the development of free-flowing bores throughout the GAB (GAB Consultative Council 1998). Prior to development, the GAB was in a steady-state condition. Over the last 110 years, there has been a visible reduction in flows and extinctions of individual springs. Habermehl (1980, 1982, 1996) has extensively documented hydrogeological changes; summaries are given in Boyd (1990) and Harris (1992). The SA Government has almost completed a bore rehabilitation program, started in 1977, to limit wastage from pastoral bores and to manage pressures in the SA portion of the GAB margins (Sibenaler 1996).

The known relations between water extraction and spring responses have been investigated in environmental assessment for the Olympic Dam development, particularly in Kinhill Stearns (1984) and in the EIS for the Olympic Dam expansion (Kinhill Engineers 1997). Since the development is politically contentious, many of the findings are politically contentious also, regardless of their scientific validity. It must be acknowledged that the location of the present main borefield (Borefield B) for Olympic Dam was selected in part to minimise impacts on the springs (Kinhill Engineers 1995).

The difficulty as regards spring management lies in partitioning the effects of drawdown from other factors, other than where drawdown has clearly resulted in the total extinction of a spring. In particular, responses to removal of stock almost totally obscure responses to drawdown influences, and themselves may result in a reduction in apparent flow at springs. Tarlton spring group (Appendices) provides a pertinent example of an almost complete cessation of flow resulting from the exclusion of stock and independent of any known regional drawdown effect.

2.4 Perceived special values associated with mound springs

2.4.1 Social

Cultural heritage

Regardless of the specific outcome of future Native Title determinations, springs retain Aboriginal importance. Hercus and Sutton (1985) recorded numerous ethnographic sites within the limited area between Marree and Curdimurka, forming part of Dreaming Tracks in the region:

> "Mound spring ethnographic sites have specific significance to the current traditions of Aboriginal people in the region. Sites...are almost universally associated with the water resources of the springs.
>
> "...Initiations and ceremonies relating to these Dreamings, in which some Aboriginal people alive today have participated, have been performed on many occasions. As a result, they have traditional responsibility for the protection and maintenance of the ethnographic values of the sites and localities"

Kinhill Engineers (1997), p6-4

The importance of archaeological sites associated with springs has already been discussed (above). We emphasise that the sites are not in any way a renewable resource, and that they may be subject to damage from stock, visitors and infrastructure construction.

European and "Afghan" heritage associated with springs is similarly important. It includes early pastoral infrastructure, particularly the old and abandoned troughs, walls and catches; the remnants of the Overland Telegraph, ranging from ruins to remnant telegraph posts; the relicts of the Ghan railway; and the paths of the "Afghan" cameleers. Part of the heritage includes alien plants, particularly the date palm and bamboo. In the context of spring biology, these are alien weeds. In the context of the history of the region, they are relics, no less than ruins of the course of settlement and, often, abandonment.

Tourism, ecotourism and education

Springs are a specific focus within the increasing levels of popularity of outback tourism generally, and the increasing emphasis on ecotourism. While there are no formal records, it is obvious that visits to the well-known Blanche and Bubbler springs in Wabma Kadarbu Conservation Park are numerous and increasing. It is also evident that tourist visitation to other springs would be higher if people were aware of their location.

Values for tourism, and for education, represent a dilemma. It is obvious from Blanche Cup alone (Appendices), that trampling damage at least accompanies visitation, hence the need for provision of boardwalks and similar facilities. Potential values are thus at risk from the activity for which the potential is perceived. Harris (1992) highlights this conundrum at Dalhousie Springs.

2.4.2 Biological

Evolutionary

Mound springs represent mesic, wet islands in a normally arid landscape, the analogy being "oases in the desert" (Harris 1981). A consequence has been the isolation of animal and plant populations, which cannot survive without the permanent spring waters and which cannot readily disperse elsewhere, and their subsequent evolution in isolation, resulting in the presence of narrow endemic species.

There is a single endemic plant species recorded for the South Australian mound springs.. The salt pipewort *Eriocaulon carsonii* is a member of a widespread largely tropical to subtropical genus of some 400 species. It is very rare indeed, limited to populations near Hermit Hill, north of the Flinders Ranges, near Louth (NSW), Elizabeth Springs (Qld) and springs on the far eastern margin of the GAB in Queensland. There are morphological differences in collected specimens from some localities. As well as the evolution of an endemic species in the spring, there may be evolutionary differentiation occurring between its widely separated occurrences.

Two fishes are endemic to springs, the Dalhousie catfish *Neosilurus* sp. nov. 1 and the Purple-spotted Gudgeon *Mogurnda* sp (Glover 1990). The first is present at both Dalhousie Springs and Old Nilpinna, the latter at Dalhousie only. Seven other fish species have been recorded in mound springs but are not restricted to the springs

The invertebrate fauna associated with mound springs displays a high degree of endemism. Spiders have only recently been the subjects of examination, other than the early records of Greenslade (1985). It appears that there may be an unknown number of spider species endemic to spring wetlands (Lamb 1998; Kinhill Engineers 1997). Spiders while dependent on the maintenance of wetland do not necessarily require the presence of free water.

Crustaceans endemic to the springs are an ostracod *Ngarawa dirga,* the amphipod *Austrochiltonia* sp. and the aquatic isopod *Phreatomerus latipes.* All are widespread in the study area (Appendix M), although preliminary genetic research suggests the possibility of *N. dirga* at least being an "umbrella" for a group of undetermined narrow endemic species. All require free and generally flowing water: Kinhill Engineers (1997) suggest that stock or pest animals adversely affect the ostracod and the amphipod species.

The outstanding example of evolutionary processes in operation is that of the freshwater gastropod snails of the family Hydrobiidae (hydrobiids). Ten endemic species within two endemic genera, *Fonscochlea* and *Trochidrobia,* have been described within the present area of interest (roughly, the Lake Eyre Supergoup) (Ponder et al. 1989, 1995). Distributions of species in spring complexes is given in Appendix M. A further three species in two genera have been described for the Dalhousie Springs region (Ponder et al. 1996). All species are listed by the IUCN as threatened or near threatened (IUCN 1996).

All but a single amphibious species of hydrobiid species are fully aquatic, needing free water to survive. Loss of free water at a spring is enough to cause the local extinction of that spring's population.

Biogeographical and general biodiversity

As well as the development of endemism, the springs permit the maintenance of relict populations of species which would otherwise not survive in the arid surrounds. Of the plant species, *Gahnia trifida*, *Baumea juncea* and *Juncus kraussii* are all present as island populations, far disjunct from their major, near-coastal distributions in southeastern Australia. Their significance lies in the existence of the disjunct populations: loss of spring populations would not threaten the survival of the species generally. Other species are less disjunct, but still separated from their major populations (eg *Samolus repens*).

In terms of biodiversity generally, the springs are not highly diverse ecosystems. Indeed, a diverse ecosystem should not be expected, given the small-island nature of springs. The aquatic and semi-aquatic flora on the springs is depauperate (as indeed is the aquatic fauna). Symon (1985) listed over 300 species for the general area covered in his reconnaissance, of which less than 15 were specific to springs. Similarly, Mollemans (1989) listed over 100 species associated with Dalhousie Springs, of which about 20 were aquatic or semi-aquatic and directly dependent on the spring waters.

The contribution of springs to regional biodiversity is not a function of species counts, but arises from:

- the existence in an arid region of permanent wetland habitats,
- the relatively few species dependent on those habitats which otherwise would not be present, and
- the island biogeographical and evolutionary processes demonstrably in operation.

The island processes are perhaps their most significant contribution: the springs provide an accessible evolutionary and ecological laboratory (Ponder 1985, 1986; Ponder et al. 1995).

2.4.3 Physical

Climatic variation insights

Where springs have trapped layers of sediment, or developed fen deposits, there exists a record of climatic fluctuation provided by both the sediments themselves and the pollen within them (Symon 1985). This is a largely unutilised resource, potentially capable of yielding real information on climatic variation in the recent past. Boyd (1990, 1994) has undertaken some pollen analysis from Quaternary sediments at Dalhousie. Habermehl (1985) cored and described carbonate mound deposits. However, there has been no close examination of the very recent deposits of the unconsolidated fen and silt deposits evident in many of the springs (Figure 2.5). The near-surface layers however can be totally mixed by stock pugging and miring.

Geological and geomorphological

The requirements for groundwater use and impact assessment associated with Olympic Dam has spurred extended hydrogeological study. Generally, however, the physical aspects of the existing mound springs have been overshadowed in conservation management by the biological aspects. Although the multiple forms of mounds have been cited as reasons for conservation (eg Harris 1981, Greenslade et al 1985), the presentation has been of something static, and biological aspects given more weight (eg in Social and Ecological Assessment 1984). There is a need for more evaluation of the range and variety of mounds, particularly given that mounds physically can be easily damaged, by stock or other human agency. In the case of travertine or tufa mounds, or limestone terraces, such damage is essentially irremediable.

Geomorphological processes in the mound springs may be more dynamic and on a shorter time scale than previously realised. Since monitoring of springs near Hermit Hill commenced in 1983, there have been several examples of totally new springs appearing and apparently extinct travertine platforms developing vents. Most of the new appearances disappeared equally rapidly but some remain, one being now a major spring with a high flow rate. Linkages between observed changes in flow and local seismic disturbance are also apparent.

While there is recognition of the geological and geomorphological values of the springs, this does not seem to be given the same level of attention as applied to the biology. We suggest that this is a function of lack of research activity in the former.

Figure 2.5 Unconsolidated mound cut by 1984 floodwaters, Hermit Springs.

Mound alternately layered with fen and silt deposits, extending below the pool surface.

2.5 Perceptions and actuality of influences of domestic stock

2.5.1 Assumptions on the role of stock

Conservation management of springs to date has primarily relied on exclusion of domestic stock; hence the reservation of Witjira National Park and the DEHAA fencing program. The basic assumption is explicit: "There is no doubt that stocking has a gross and generally deleterious impact on mound springs" (Harris 1992). Similar statements on the influence of stock are made in both the impact assessment literature (eg Kinhill Stearns Roger 1982; Fatchen & Associates 1983; Kinhill Stearns 1984) and the research literature (Ponder 1985, 1997). That impacts are significant is undeniable. That all impacts are generally deleterious is arguable, especially in relation to vegetation. That removal of stock will automatically enhance the survival of spring values is, simply, wrong.

Stock use of springs is variable, in both space and time. Isolated springs are more heavily utilised by stock than individual springs within large assemblages of springs. Small wetlands suffer more trampling than large wetlands (Kinhill Stearns 1984, from Fatchen and Associates 1983). Hence an isolated vent such as The Vaughan shows very heavy stock use while most of the numerous springs in the extensive Francis Swamp group show very light stock use. Stock use is greatest in drought and least in periods of pasture growth. Perceptions of the condition of a given spring in relation to cattle effects will vary depending on the time and place of the observation.

2.5.2 Stock in relation to aquatic fauna

There is evidence of recent extinctions of hydrobiids in some spring groups, which may be linked to stock (Ponder et al. 1995, 1996). Zeidler and Ponder (1989) also comment on dangers of "destruction by stock".

Severe trampling in an isolated spring might well eliminate hydrobiids. The difficulty however is that other factors may also contribute, and there is no certainty that stock trampling was the actual cause. The extinctions may have resulted from temporary flow cessation, which can be brought about by vegetation in the absence of stocking, or due to local drawdown from nearby bores, or a consequence of the general reduction of the GAB turning adequate habitats, with plentiful water, into marginal habitats with little water. In the last case, a severe drought could result in a temporary loss of surface water without further flow reduction, influence of vegetation or stock effects.

Hydrobiids have recently disappeared from Emerald Spring (Darren Niejalke pers. comm.). The disappearance is roughly coincident with artificial burning of the spring at a time of heavy stocking pressure on the spring tail. Multiple scenarios can be envisaged, for example burning killing the spring population, stock pressures simultaneously killing the tail population, and no third source present for recolonisation of either.

There simply does not exist as yet a sufficiently replicated and long period of direct monitoring to allow clarification of the factors controlling local hydrobiid populations. The same is true of other invertebrate groups. Although evolutionary and biogeographic research has continued for some decades, the necessary research on the micro-ecology of the organisms has only really commenced in the last five years, and findings present more questions than answers (Niejalke 1998 - Appendix N).

Grazing is now known to affect spiders of mound springs. Influences are neither disadvantageous nor advantageous, but rather, manipulative. Vagrant hunting species are advantaged by mowing and trampling; web-building species disadvantaged (Lamb 1998). Similar responses might well emerge amongst the aquatic fauna.

2.5.3 Stock in relation to plant diversity and richness

Approaches to management of springs to date have assumed that stock result in reduced plant diversity (eg Social and Ecological Assessment 1984, Symon 1985). Where data exist, it is clear that stock reduce the total biomass, alter the vegetative structure and change the competitive relations between species. This does not automatically mean a reduction in diversity or richness. Fatchen and Fatchen (1993), from the basis of the most extensive monitoring examination of spring vegetation in relation to stocking, concluded that:

- Stocking does limit the cover and biomass of vegetation
- Stocking does not significantly affect the total species richness of a whole spring group, but may depress the species richness of individual wetlands within a spring group
- There are no data for or against the common assumption that stocking may have eliminated species from smaller spring groups. The main control on plant species richness appears to be the number and compactness of springs within a spring group. Available data suggest that springs under domestic stocking may be marginally richer in aquatic species than those released from grazing.
- Stocking suppresses (without wholly eliminating) some species and advantages others. The endemic rare species *Eriocaulon carsonii* and the common *Cyperus laevigatus* are advantaged by stocking, with populations declining following stock removal. *Phragmites australis, Typha domingensis, Baumea juncea, Gahnia trifida* are all disadvantaged. The

sedge *Fimbristylis dichotoma* is disadvantaged both by stocking and, subsequently, by the growth of other species in the absence of stocking.

They also found that species diversity on springs was at its highest during the transition from a long-term stocked state to a long-term unstocked state. For springs released from domestic stocking, a *decline* in diversity in the long-term was evident, and indeed could be expected as a new dynamic equilibrium established. These findings were partially reported in Badman (1991): Harris (1992), commenting on Badman (1991), pointed out that the advantage of *E. carsonii* under stock "begs the question of floristic dynamics in the pre-European environment".

The interactions between stock, plant biomass, dominance and diversity changes, and spring flows is central not only to understanding why the fenced springs have changed as they have, but also to the management of springs generally. The DEHAA fenced springs are a clear demonstration that protection of springs from stock does not necessarily result in a high diversity outcome. The mechanisms are examined in detail in Section 3.

2.5.4 Cultural eutrophication

Organic pollution by stock of the small spring water bodies is frequently cited as a potential major impact (eg Mitchell 1985), with algal mats in particular cited as evidence for potential de-oxygenation. Kinhill Engineers (1997) indicates that there is evidence that most aquatic invertebrates are adversely affected. The data however are scanty. Mitchell (1985), in raising the possibility, also pointed out that spring waters can be naturally high in nitrogen without invoking defecation and urination by stock. There are further reasons why cultural eutrophication may not be as significant as might be assumed:

- Springs flow. For the same reason that salts carried in the spring water do not simply stay and concentrate in the spring, but are carried off it, organic pollution by stock also must wash out.
- The majority of springs have very shallow water bodies, often only a film. Oxygen levels will therefore be high (Mitchell 1985).
- Mats of filamentous algae, often considered to indicate cultural eutrophication, appear from time to time on both grazed and ungrazed springs.
- Some sedges, particularly *Cyperus laevigatus*, "hay off" and die for no immediately perceptible reason. Observations since 1983 (Fatchen and Fatchen, in prep.) indicate this to be a random occurrence. The dead material decomposes *in situ*, representing a significant deoxygenation load.
- *Phragmites australis* and to a lesser extent *Typha domingensis* die back in winter, especially when subject to frost. Leaf material decomposes on the vent, again another significant de-oxygenation load.
- Many of the springs show long-term fen (peat) development. By definition, this also is a long-term de-oxygenation process.

Where cultural eutrophication may come into play is in areas churned or pugged by stock, where flow is impeded, and on the ends of spring tails where water may be almost stagnant.

2.5.5 Physical damage

Regardless of the view taken on their biological impact, stock use of springs has direct physical impacts. Physical impacts affect physical aspects of spring deposits which are either non-renewable, or renewable only on a very long time scale.

The following short list of examples of physical damage comes from either monitoring supported by WMC or monitoring associated with the DEHAA fencing program.

- Breaking of travertine overhangs on conical mounds (eg Horse Springs)

- Damage to limestone terraces (eg Strangways, Coward, and the Kewson Hill - Elizabeth - Jersey groups).
- Breaking of silty mound edges and slopes, affecting or initiating spring tails and changing the water levels held in vents (eg new tails at Buttercup; breakdown of mound surrounds at The Vaughan; breakdown of the edges of the incised tail at Big Cadna-Owie)
- Numerous cases of miring of cattle, for example in springs along the Finniss Creek course near Hermit Hill up to 1983; in Fred Springs; "devastation" (Harris 1992) of the vent at The Fountain by cattle trapped within the exclosure.

Damage to limestone and tufa sediments is not repairable on a human time scale. The rate of breakdown is far faster than the rate of building, particularly where there have been clear flow reductions over the last century and the building processes in operation are minimal or have stopped, as in the first two cases.

Damage to silty mounds is repairable on a human time scale, through vegetation growth and accretion of flood- or wind-borne sediment, but only if the damaging agent is removed.

Pugging and especially miring of stock over a century of use is likely to have already totally confused the sedimentary and pollen record of the recent past in most springs. There may still be sufficient differentiation remaining to provide future input on recent climates. If so, continued pugging and miring will ensure that, eventually, this non-renewable information resource will be totally lost.

The impacts of pugging, miring and breakdown of spring-developed mounds and terraces provided further reason for the SA Government fencing program, and for other, later stock exclusion projects undertaken with the assistance of pastoral lessees. For example, exclusion fencing of the terraces at Strangways was undertaken in 1996 by S Kidman & Co to prevent further damage to the terraces themselves, as well as protection of a local population of the rare terrestrial plant *Hemichroa mesembryanthemum* and springs within the terraces.

An additional consideration favouring stock exclusion is physical damage to cultural resources associated with the springs, particularly the scattering and mixing of archaeological material, both Aboriginal and European.

Generally, protection from stock has been argued for biodiversity reasons, with physical damage almost as an afterthought. Yet the physical effect of stock involves demonstrably non-renewable resources, and can be unarguably viewed as deleterious. The influences of stock on biodiversity, however, are not clear-cut at all.

3. ECOLOGICAL DYNAMICS IN SPRINGS

3.1 Significance to management

Much of the emphasis in protection of mound springs has been the removal of stock, whether by reservation as National Park (Witjira National Park, Wabma Kadarbu Mound Springs Conservation Park) or the fencing of individual springs. Biological values have weighed heavily in arguments for fencing (eg Social and Ecological Assessment 1984, Greenslade *et al.* 1985, Kinhill Stearns 1984).

Exclusion of stock is a passive form of management, in effect a single treatment (assuming stock to be permanently excluded). Imposed on a dynamic biological system, it cannot be expected to preserve the state of that system at the time of fencing. It is more likely to result in a change to some other state. From existing models of the ecological dynamics of springs, it is possible to predict the most likely states resulting from stock exclusion. These states are generally variants on a combination of increased biomass, decreased diversity and apparent flow decrease, evident in many of the fenced springs (Harris 1992; Appendices).

Ecological models of the springs also indicate means whereby particular states may be achieved and maintained. All means involve active manipulation, always a controversial topic in perceptions of biological conservation.

3.2 Ecological dynamics model

3.2.1 Background

Most current knowledge of the ecological dynamics of springs derives from the combination of biological, hydrological and hydrogeological information developed through environmental assessment and monitoring procedures associated with the Olympic Dam development, funded by WMC Resources Ltd and subsidiaries. Most is based on the vegetation community, a consequence of the early design and application of extended but also highly replicated baseline survey, maintained in subsequent monitoring, allowing both the construction and testing of predictive hypotheses (Fatchen and Associates 1983; Kinhill Stearns 1984; Lange and Fatchen 1990; Fatchen and Fatchen 1993, in prep.).

In contrast, ecological dynamics of the spring fauna are poorly known, and many groups, for example spiders (Lamb 1998), have yet to be fully described. Although baseline inventory and monitoring of the aquatic invertebrate fauna has been undertaken as part of the Olympic Dam investigations (Kinhill Stearns 1984, Kinhill Engineers 1997), it is only since 1995 that studies have been initiated at the level of replication and intensity likely to provide future predictive detail on faunal groups (papers and Narration in Niejalke 1998 (Appendix N); WMC (Olympic Dam Corporation) 1998).

The vegetation studies (Fatchen & Associates 1983; Fatchen and Fatchen 1993) have provided a series of conceptual models which have been successfully tested through repeated monitoring. Fortuitous events, particularly the removal of domestic grazing from Finniss Springs Station, fluctuations in feral grazing, floods, the reservation of Wabma Kadarbu park, and some fires, have all permitted testing of hypotheses. Active experimentation, though highly desirable and recommended, could not be undertaken due to public and other sensitivities surrounding the issues of water supply to the Olympic Dam development.

The conceptual models provide the best current framework for understanding the mechanisms, including feedback mechanisms and interactions, controlling species richness and diversity, biomass and community structure, apparent flow and wetness, and variation with time. They allow the qualitative prediction of responses to disturbance generally, and particularly the influences of grazing and fire.

3.2.2 Model limitations

Development of the conceptual models incorporated data from springs throughout the southwestern margin of the GAB, particularly the data in Symon (1985) and unpublished data (TJ Fatchen) for springs west of the Denison Ranges. However, the core data derives from the Olympic Dam environmental studies within the Marree-Blanche Cup region. Subsequent hypothesis-testing and modification has also been limited to this region (Fatchen and Fatchen 1993). Hence only part of the variation in springs outlined in Section 2.2 is covered. In particular, by far the bulk of data comes from springs fed by the eastern, carbonated waters, with the associated influences on species distributions and mound building as discussed in Section 2. Extrapolation of models to the western, sulphated-waters springs needs a degree of caution.

Nevertheless, the changes of most concern in the fenced springs - increased biomass, decreased diversity and decreased apparent flow - are all predictable from the model. Differences in detail relate to the majority of fenced springs being high-flow springs, and the changes in importance of some spring species relating to water chemistry differences (Section 2.2.3).

As regards the spring-dependent fauna, the most that can be said is that free surface water of reasonable quality appears to be the key to maintenance of the aquatic invertebrate groups dependent on springs. This particularly applies to the hydrobiid snails, which provide the most outstanding demonstration of evolutionary processes and show the highest degree of local endemism. There is as yet no basis to infer the effects of management on fauna other than this general requirement for free water, and an indication that non-aquatic but spring-dependent groups such as spiders may have other requirements.

3.2.3 Interactions at the level of a spring group

Maintenance of diversity through colonisation and extinction

From the information and data in Symon (1985), and a single survey of some 250 springs as part of Olympic Dam environmental assessment in 1983, species richness and diversity was demonstrated to be related to the number of springs in a group rather than to area of individual wetlands. Dominance alternations, where physically identical, adjoining springs are dominated by different species, were commonly observed. Although groupings of particular species were detectable, these did not conform to an orderly sequence of species associations relating to flow, age of spring, or interspecific competition. Fatchen & Associates (1983) drew the following inferences:

- Orderly and predictable species succession was not occurring (vegetation processes were stochastic, not deterministic).
- Random colonisation and extinction processes were largely responsible for the species composition of spring groups. In particular, the rare narrow endemic *Eriocaulon carsonii* was a highly opportunistic species.
- "Scramble competition", whereby the first species to colonise "wins" the limited resource, was in play (Lange and Fatchen 1990)
- Springs generally had to be highly dynamic in a physical sense, to provide continued opportunities for colonisation regardless of competitive differences between species which could normally be expected to result in competitive exclusion.
- Dynamics had to be on a relatively short timescale, of a few years or less, and not on the geological timescale usually put forward (eg in Greenslade et al. 1985).

These findings were incorporated into the synthesis of mound spring studies provided by Kinhill Stearns (1984). They provided the best fit to the then available data. Especially, they provided a reasonable explanation why species richness should relate to the number of springs and not their area, and why *every* wetland species was found to dominate at least some vents, despite the obvious disparity in competitive abilities. Further, the inferences could all be extended to form hypotheses testable through monitoring. Over a short time span, there should be:

- Multiple and frequent examples of local colonisation and extinction, with a high degree of randomness, and displays of opportunistic behaviour in *Eriocaulon carsonii* particularly
- Evidence of scramble competition through the appearance of differing dominant species in equivalent circumstances
- Major physical changes in springs.

All have been clearly demonstrated (Fatchen and Fatchen 1993; WMC (Olympic Dam Operations) 1996).

Physical and other factors maintaining colonisation opportunities

In retrospect, the main limitation of the baseline inferences was insufficient account being taken of the role of stock in maintaining the opportunity for scramble competition to occur, and in reducing the competitive advantages of *Phragmites australis* in particular (Fatchen and Fatchen 1993). The role of stock as a disturbing agent is discussed in more detail below. Stock removal from the Hermit Hill area between 1983 and 1986 directly resulted in a wave of colonisations, competitive exclusions, local extinctions, dominance and diversity changes.

At least two cases of each of the following physical changes, unrelated to stock effects, water extraction effects, or other human intervention, have been recorded within the Marree-Blanche Cup area monitored as part of Olympic Dam environmental programs (Fatchen and Fatchen 1993, in prep.; WMC (Olympic Dam Operations) 1996):

- Appearances of totally new vents in areas lacking wetland vegetation, with subsequent colonisation and growth (two known cases).
- Appearances of new vents on extinct mounds, with subsequent colonisation and growth (multiple cases and most only transient, but including one vent in West Finniss spring group with a flow estimated to be above 2 L/s).
- Disappearance of all trace of vents and their vegetation following flooding (two known cases)
- Major changes in spring geography, particularly the location of tails (numerous cases, frequently occurring).
- Wildfire, either lightning strike or spontaneous combustion (two known cases)

These cases may appear proportionately minor. The monitoring for Olympic Dam extends over some 350-400 sampling units, representing some 250-350 discrete springs, over a span of some 15 years. The proportion, however, is significant if viewed in demographic terms (eg in analogy to birthrate measured per year, per thousand population). The point is established that springs are physically dynamic even without human or stock agency.

Role of dispersal and competitive abilities

Species must first get to a new colonisation opportunity. Clearly, species with better means of dispersal are more likely to arrive first, and hence have the chance to develop and dominate first. Their advantage is greatest where opportunities are infrequent and far apart, as with isolated or physically static springs, and least where opportunities are frequent and close, as with compact groups of numerous springs subject to physical change.

Species already present when a colonisation opportunity arises, whether following physical disturbance or its cessation, will be at an initial advantage over later arrivals, even though the later arrivals may be capable of subsequently displacing them.

The spring-specific plant species have widely differing dispersion and competitive abilities. On present information, *Typha domingensis, Phragmites australis* and *Cyperus laevigatus* are the most easily dispersed, and *Gahnia trifida* apparently the least easily dispersed (Fatchen and Fatchen 1993).

Both *Typha* and *Phragmites* have the ability to totally displace other species, through overshadowing, control of the water supply, or other mechanisms for competitive exclusion. Bamboo and date palm, both aliens, also can totally displace others. *Cyperus laevigatus, Cyperus gymnocaulos* and the endemic *Eriocaulon carsonii* are opportunistic species: all have been recorded as dominating some wetlands at some stage (Symon 1985; Fatchen and Fatchen 1993) but there is no case where these species have actually excluded other species from a wetland. Rather, most cases of their dominance relate to the exclusion or limitation of other species by external mechanisms, in particular domestic and feral stock.

Management of colonisation opportunities

The importance of colonisation opportunities is a challenge to spring management. It is now clear that the processes which maintain richness, and to a lesser extent diversity, operate at the level of a spring aggregation, not at the level of an individual spring. It follows that management has to be aimed at the group, not the individual spring.

The survival of *Eriocaulon carsonii*, for example, depends not only on where the species might be now, but also on where it is going to be next. To protect it requires protecting its colonisation opportunities and processes. To manage it requires managing those opportunities and processes. Neither protection nor management may be achievable by passive means. The same may be said for protection and management of plant diversity generally. We expect that similar requirements will appear for aquatic fauna, once studies currently under way deliver sufficient information.

3.2.4 Interactions at the level of a single spring

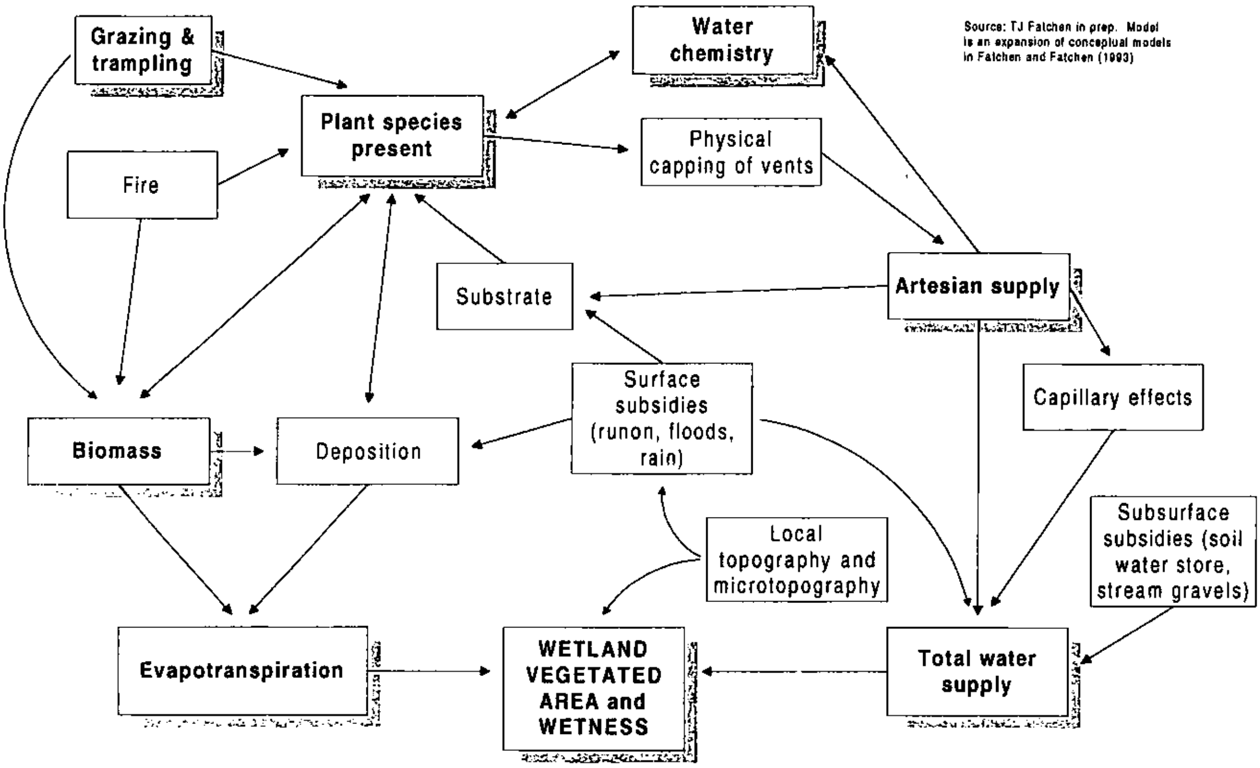
Figure 3.1 shows the web of interactions influencing a spring. Questions of what plants are present, in what quantity, what the apparent (surface) flow may be at a spring, and what modifying influences are in play, are all interconnected. Issues are complicated by multiple feedback loops (double-ended arrows in Figure 3.1).

Modifiers to artesian supply

Apart from the requirement to actually have an artesian supply for an artesian spring to exist, there is *no simple link between the artesian supply and actual dynamics of a spring.* The total water supply to a spring will be affected by surface and subsurface water subsidies, hence the appearance and maintenance for two years of flowing vents in the extinct Fred West spring group, following major floods in 1989 (Fatchen and Fatchen 1993). Similarly, expansions in vegetated wetland are recorded in wet years, and contractions in dry years, without reference to any stock effects (WMC (Olympic Dam Operations) 1998).

Artesian flows can be halted, or severely diminished, by the development of rhizome caps, a species-dependent effect. Species for which vent capping has been recorded are *Typha domingensis, Phragmites australis, Gahnia trifida,* bamboo, date palm, and *Baumea juncea.* The last creates "quaking bogs", mats of vegetation suspended over a pressurised bubble of water and mud. At the extreme, no water at all may be evident at the surface. More usually, some seepage occurs at the edge of the vent.

Figure 3.1 Ecological interactions on a mound spring.



Modifiers are most pronounced where artesian flows are small: on present information, below about 0.2 to 0.3 L/s. This range includes the majority of individual springs, but excludes most of the DEHAA-fenced springs. At higher artesian flows, the influence of surface and subsurface subsidies is proportionately reduced. Further, where vent capping does occur, the most common response is the appearance of a new or subsidiary vent on the mound. As well as the numerous examples found in the larger spring groups monitored as part of the Olympic Dam investigations, new vents have also appeared in some of the DEHAA-fenced springs following vent capping (Appendices).

Evapotranspiration, water supply and apparent wetness

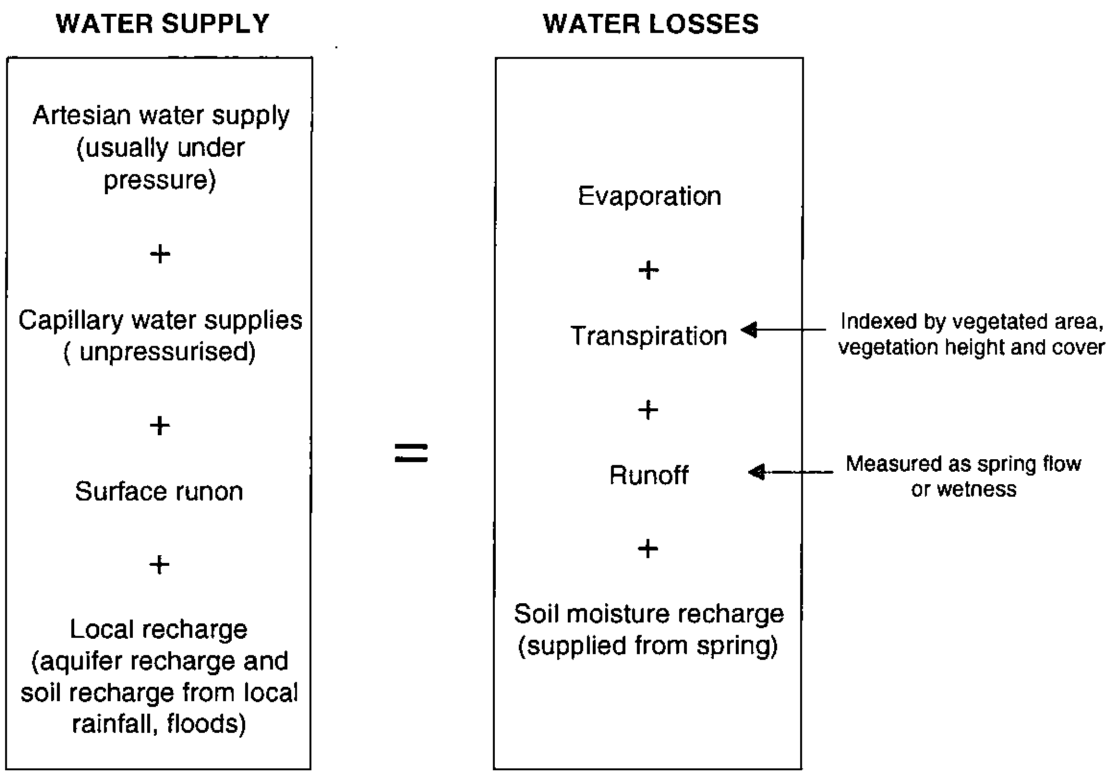
The water balance for a mound spring is summarised in Figure 3.2. In the absence of other limits, plant biomass will increase on a spring until evapotranspiration is equivalent to the water supply. At this point, a spring would be maintaining wetland vegetation at high biomass, with no free water evident. This end-point is reached in springs with a very small artesian supply, *and which are not subject to any form of disturbance.* The interaction can easily be mistaken for the effects of aquifer drawdown.

Numerous possible combinations can be constructed using the interaction model of Figure 3.1. The following is the most common scenario (Fatchen and Fatchen in prep.), and is evident in the photographic monitoring series for Tarlton (Appendix H).

- The spring mound initially has abundant free water (the apparent flow of the spring) and a low plant biomass. This is the situation for all new vents, or for existing vents where some form of disturbance has resulted in low plant biomass.

Figure 3.2 Mound spring water balance

Source: Fatchen and Fatchen (1993)



In the absence of other limits, plant biomass will tend to increase until:

Evaporation + Transpiration = Water Supply

and

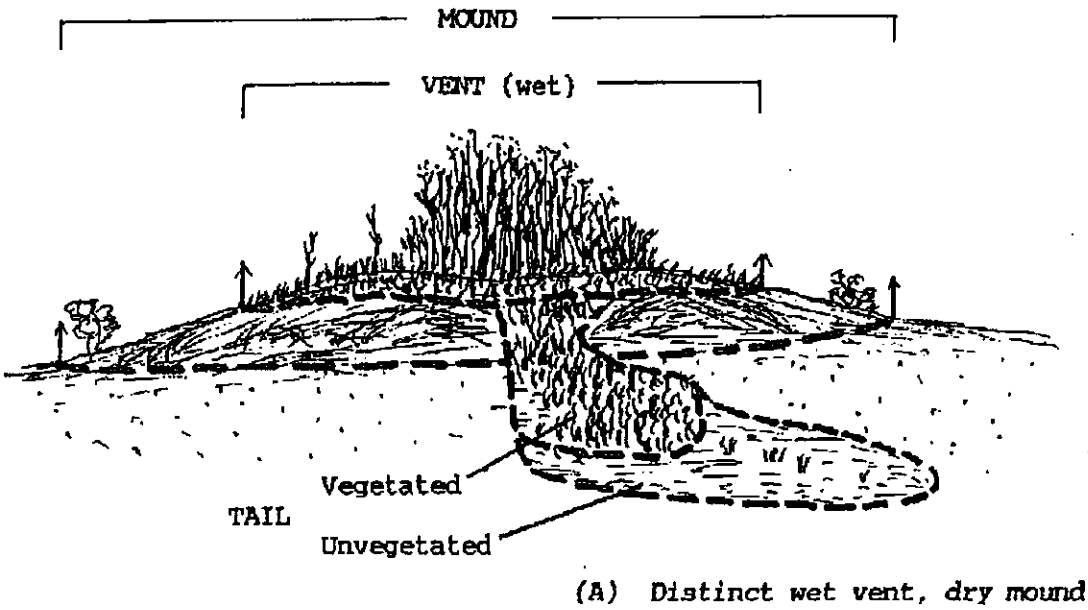
Runoff (flow or wetness) tends to zero

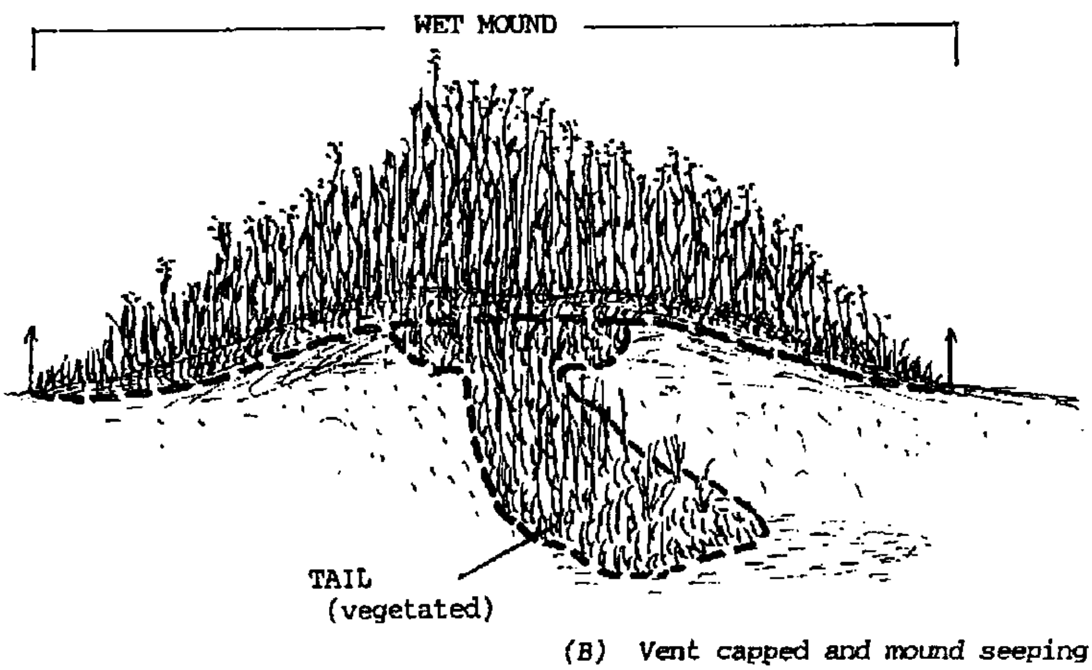
- Species capable of generating a high biomass are either present in small quantity or invade and establish. Usually, these are one of *Phragmites australis* or *Typha domingensis,* both of which have extremely good dispersal abilities and, in the absence of disturbance, a competitive advantage over other mound species in the majority of situations.
- Initially, water is non-limiting and the species expand in both area and biomass. The transpiration loss increases with the biomass, and net evapotranspiration also increases, even though simple evaporative losses may be reduced.
- Vent blocking by rhizome or tuber development may result in an initial expansion of the area and opportunities available for colonisation, by seepage on the perimeter of the original vent or the appearance of distinct subsidiary vents.
- The species transpiration demand, and further vent blocking, continues to reduce the apparent flow from the spring, and shortens any tail which might extend from the vent, while at the same time the colonising species are still expanding (Figure 3.3).

- The point is reached where free water may still be present, but not in sufficient quantity to permit further expansion. Continued growth of individuals still increases transpiration losses and vent blocking increasingly limits the artesian supply. In low-flow springs such as Tarlton, both factors "rob" peripheral individuals of water and the vegetated wetland actually contracts.

From a starting point of abundant water and little wetland vegetation, the outcome is a dense stand of wetland vegetation with little water.

Figure 3.3 Vegetated wetland expansion and vent clogging





Source: from Fatchen and Fatchen 1993

The apparent dry endpoint may also be reached in springs with a much larger supply, where combinations of plant species, biomass, plant water demand, and a depositional environment are in play:

- As biomass increases, the physical obstruction to flood or windborne sediment also increases; to a maximum height of 4.5m - 5.5m in the case of *Phragmites.*
- Windblown or floodborne sediment accumulates on the perimeter of the now dense and tall wetland vegetation; some also is trapped within the wetland vegetation. What residual water may have been visible at the surface before, is now evaporating within the deposited sediment.

The outcome again is a dense stand of often healthy wetland vegetation with no apparent sign of water, and with dryland species established around the wetland stand. Examples of this scenario include major springs in the course of Finniss Creek, and sandy mounds on embayments of Lake Eyre South.

In springs with higher artesian flows (above about 0.5 L/s), other factors may limit the extent to which increase in biomass, and hence transpiration and vent blocking, can take place. In these cases, spring tails are maintained even though vents may become a solid high-biomass and zero-diversity stand of reeds. The principle still applies, however, and the outcomes of biomass increase, as in most of the high-flow fenced springs, are an apparently reduced spring flow, an overall contraction of wetland, and a reduction in the wetness (Appendices).

Implications of reduced wetness are potentially serious for those aquatic fauna wholly dependent on the maintenance of at least some free water. A reduction in wetness from free water to simply damp will result in local extinction of hydrobiid snails. Their re-appearance will be dependent on re-colonisation from elsewhere, and their dispersal abilities are demonstrably poor (Ponder 1995). In contrast, the common wetland plant species will still survive on a spring if the surface wetness is reduced from free water present to damp only, their propagules can survive long periods of total drying, and most have reasonable dispersal abilities which allow re-colonisation from elsewhere (Fatchen and Fatchen 1993).

The possibility of reducing biomass to increase wetness is obvious. So is the potential for disturbance of one form or another to maintain, if not a particular steady state of biomass, diversity and wetness, then at least a continuous oscillation.

Competitive exclusions in plants

The most common cases of competitive exclusion on springs involve *Phragmites australis* or *Typha domingensis.* The biomass expansions which lead to decreased wetness also result in overshadowing, and in elimination of suitable substrate for other plant species.

Overshadowing arises from reed heights extending to above 5m and a foliage projective cover far in excess of 100%. Substrate elimination arises from the development of dense rhizome or tuber mats in and over the original substrate. Other species are displaced to the periphery of the expanding reedbed, and to tails where other influences may be limiting the extension of the reeds.

Peripheries are marginal habitats, and local extinctions are inevitable if the periphery actually dries. *Eriocaulon carsonii* habitat shifts following cessation of grazing and invasion of *Phragmites australis* provide the best-documented example. The expansion of *P. australis* displaced populations from vent centres to peripheries, and eventually almost wholly to tails, with an accompanying high rate of local extinctions during the transition (Fatchen and Fatchen 1993, in prep.)

Water chemistry

Apparent controls of water chemistry on the species found in springs have been described in Section 2.2.3. Additionally, the chemistry of the surface water may be subsequently affected by the plants growing on it. "Haying-off" and decomposition of *Cyperus laevigatus* and other species influences water quality (Section 2.5.4); fen development may affect the pH; and the relict *Gahnia trifida* generates oil slicks resembling industrial pollution (Fatchen and Fatchen in prep.). Again, where flows are high - the minority of springs - the relative contribution of species to changes in water quality will necessarily be small.

Micro-changes in water chemistry between emergence at the vent and soakage at the end of the tail may be partly responsible for the zonation of species along the tail, for example as evident at The Fountain (Appendix I).

Water temperature

Spring wetlands generally comprise the actual vent and a tail or tails, the outflow stream. In Dalhousie Springs, where initial water temperatures are high (45°C), there is a well-documented zonation of plant species away from the water source which appears to relate to a temperature gradient (inferred from Mollemans 1989). The temperature of most other springs on the southwestern margins is close to *average* ambient temperature (around 24°C) and gradients are less pronounced. Nevertheless it now appears that water temperature may play a major role in setting limits to the extent of *Phragmites australis*: the species is frost-sensitive, the region is subject to frosts, and the warmer water at a vent may buffer the individuals from frost effects (Fatchen and Fatchen in prep.).

3.3 Stock influences

3.3.1 Dynamic equilibria

From the conceptual models, multiple dynamic equilibria are possible, where one or more of the key components (highlighted in Figure 3.1) is held in a given state.

Stock maintain *one* dynamic equilibrium within the vegetation on springs. The surveys of Symon (1985), Fatchen & Associates (1983) summarised in Kinhill Stearns (1984), and Social and Ecological Assessment (1984) are all in fact describing this single dynamic equilibrium. The detail at any given time is dependent on stock intensity, itself influenced by numbers of stock, seasonal factors affecting stock use of springs, and the intensity of usage. Its general characteristics are:

- Low plant biomass: both low projective canopy cover (<55%) and low height (<30cm)
- Frequent and extended occurrences of open water
- Maintenance of frequent opportunities for local colonisations, but also actual and potential local extinctions on individual springs through grazing and trampling.
- Prevention of competitive exclusions.
- Disadvantaging of some species, particularly *Phragmites australis* and *Typha domingensis*, but also others such as *Fimbristylis dichotoma* and *Baumea juncea.*
- Advantaging of highly opportunistic species, particularly *Cyperus laevigatus* but also *Eriocaulon carsonii* both through removal of competitors and by maintenance of opportunities.
- No apparent effect on species richness at the level of a spring group, but maintenance of moderate diversity at the level of individual springs.
- Frequent oscillations in all of the preceding dependent on time, season, and numbers of stock. The unfenced spring at Outside Springs (Appendix J) provides a pertinent example.

Oscillations can be extreme. Social and Ecological Assessment (1984) reported the northern vent at Birribirriana, near Old Nilpinna spring, to have been extinct in 1983, although still carrying a dense stand of bamboo. On inspection in 1998, cattle had literally tunnelled through the bamboo, and broken the rhizomatous cap, producing a flowing spring.

Variations appear in larger spring groups as a consequence of the spread of grazing and trampling compared with the focussing inevitable on isolated springs. Hermit Springs under heavy domestic grazing in 1983 still contained high biomass springs apparently ungrazed and untrampled (Kinhill Stearns 1984). Under very light feral grazing since 1984, it still contains low biomass springs which are heavily grazed and trampled (Fatchen and Fatchen in prep.)

The exclusion of stock results in a shift to another dynamic equilibrium (Fatchen and Fatchen 1993, in prep.), with general characteristics:

- High plant biomass, involving both high plant cover (>75%) and tall plant heights (up to 5.5m)
- Reduction or elimination of occurrences of open water through high transpiration rates, vent blocking or sediment accreted by the vegetation
- Limitation of opportunities for local colonisations to those arising from natural catastrophic events (flood, fire, new vent appearances)
- Frequent competitive exclusions
- Advantaging of species susceptible to direct grazing, particularly *Phragmites australis* and *Typha domingensis.*
- Disadvantaging of highly opportunistic species such as *Cyperus laevigatus* and *Eriocaulon carsonii,* not only by limited colonisation opportunities but also through competitive exclusion.
- No apparent effect on species richness at the level of a spring group, but variation in diversity: in particular, a loss of diversity in very small spring groups or in isolated springs.
- Limited oscillation in all of the preceding dependent on occasional events such as flooding.

Increased biomass, dominance changes and decreased wetland outcomes following release from stocking are illustrated in Figure 3.4.

3.3.2 Examples of outcomes of release from stocking

West Finniss spring group

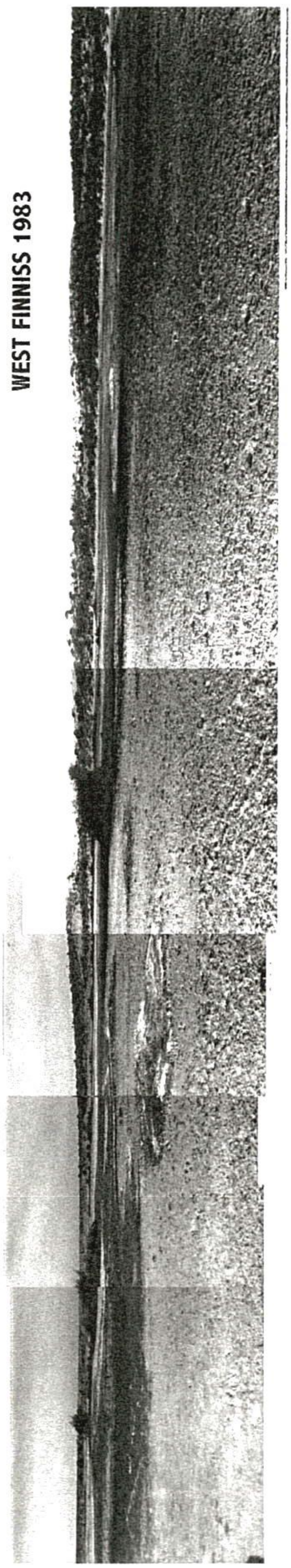
West Finniss is a large but compact spring group of between 50-60 vents. It is on level ground lacking any pronounced topographical features (Figure 3.4), and not subject to significant flooding, fire or other disturbance except the appearance of a new, very high flow vent after 1995. With these influences minimised, the group provides the clearest long-term documentation of release from grazing currently available. Data come from the highly replicated sample (Fatchen and Fatchen 1993, in prep.), monitored for WMC as part of the Olympic Dam environmental programs (WMC (Olympic Dam Corporation) 1998).

The group was subject to heavy cattle stocking in the baseline observations of 1983. Stock are understood to have been removed in 1984. Biomass increased rapidly, and the area of vegetated wetland increased as a consequence (Figure 3.5), apparently stabilising about 6-10 years following the removal of stock. The increase post-1995 relates to the appearance of a new, major vent.

Plant dominance on spring vents and on outflows very rapidly altered (Figure 3.6), with the removal of advantages and disadvantages conferred by stock, and the beginning of competitive exclusions. The major increasers were *Phragmites australis* and the relict species *Baumea juncea.* On mounds, the changes in dominance had effectively ceased and stabilised within 4 years of removal of stock, and most appeared to have occurred within two years of removal of stock. On tails, with flows affected by the increasing biomass of the mounds and more external influences in play, alterations were still occurring eight years after release from stock.

The total species richness for the group did not change. Mean species richness on individual springs and tails rose slightly but non-significantly (Figure 3.7). Species diversity, on the other hand, increased to a peak for the period of maximum changeover in dominance (Figure 3.8), then declined to levels significantly *below* those recorded under heavy stocking.

WEST FINNISS 1983



WEST FINNISS 1993

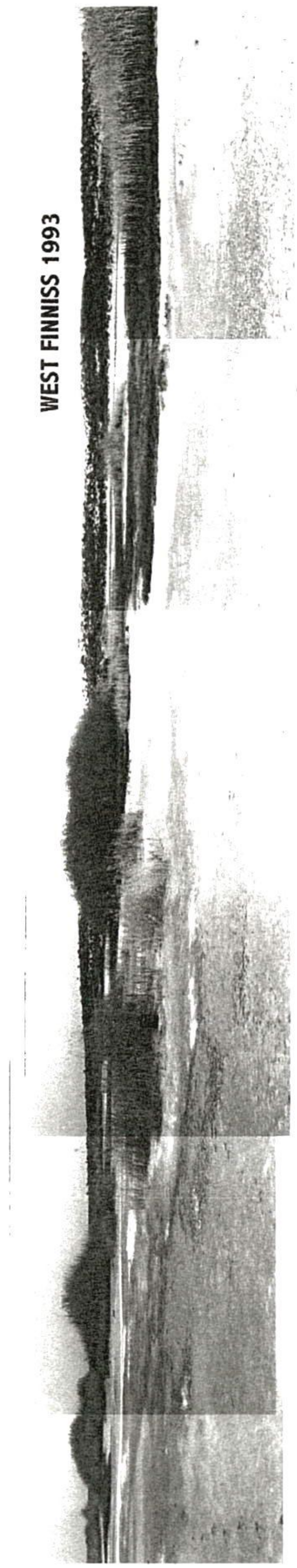
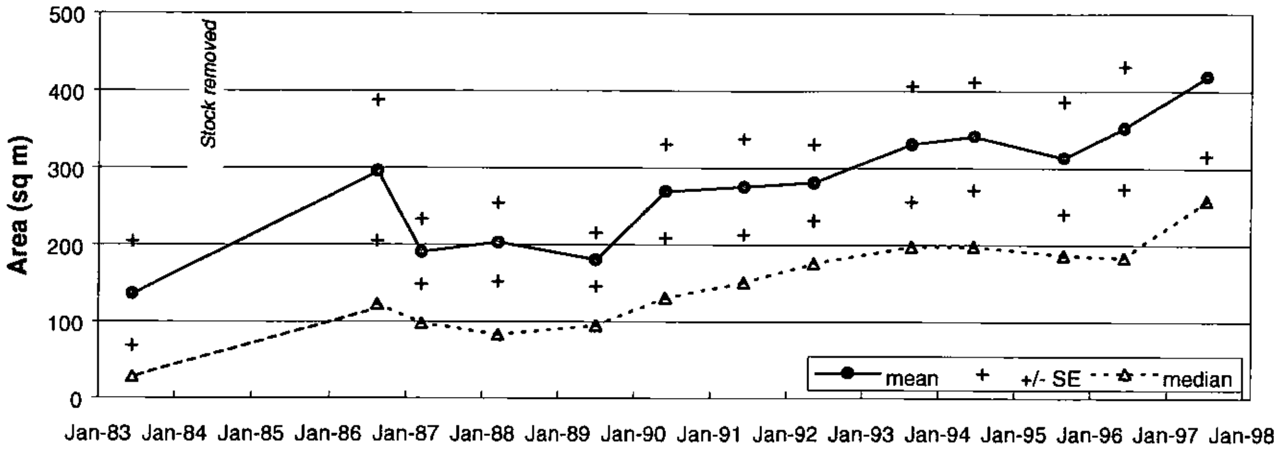


FIGURE 3.4

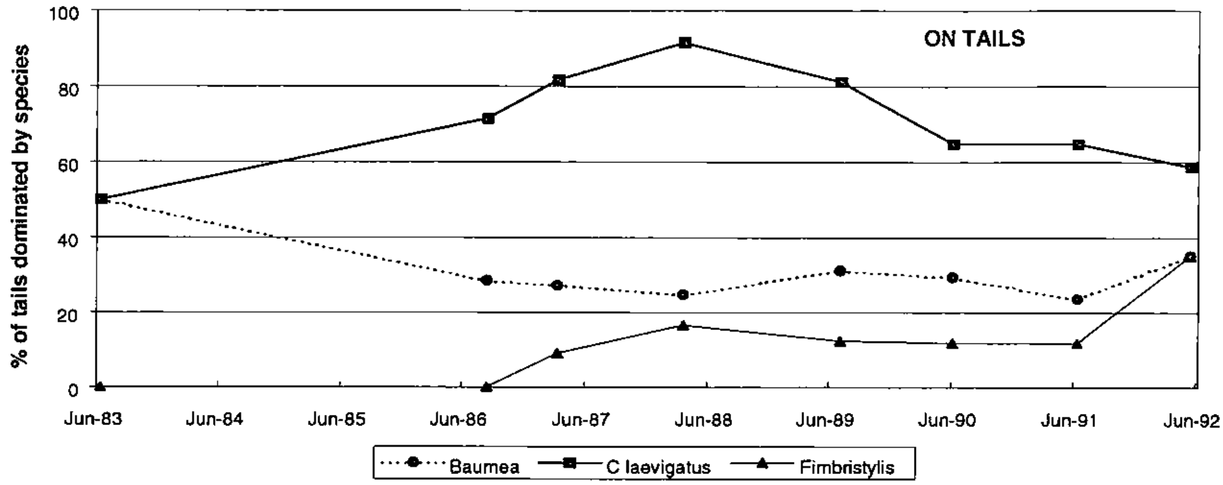
Part of West Finniss spring group under cattle (1983) and 9 years after stock removal

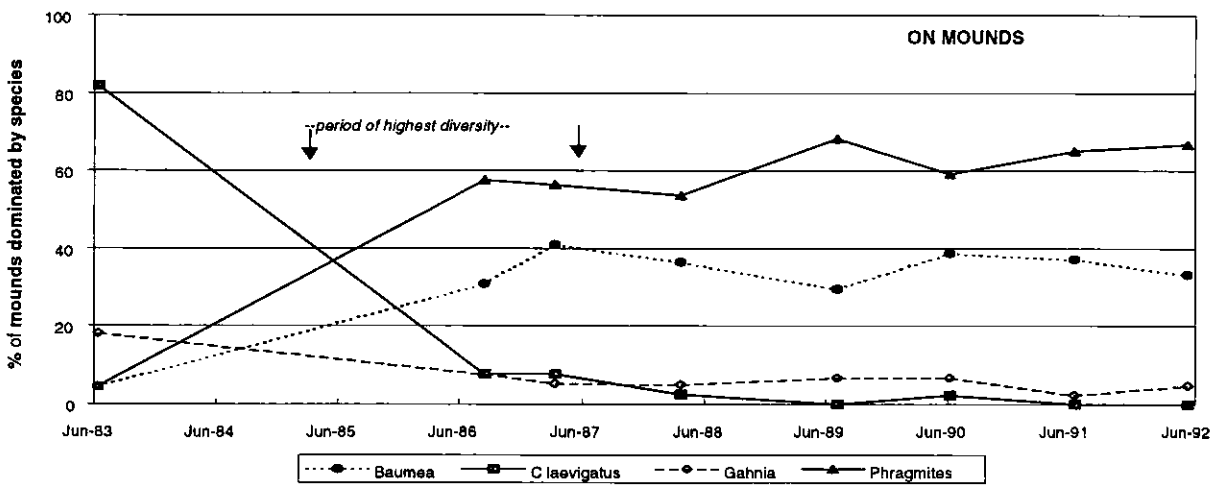
Figure 3.5 Expansion of mean and median spring wetland areas in West Finniss group following removal of stock.



Sources: Fatchen and Fatchen (1993); WMC (Olympic Dam Corporation) database; Fatchen and Fatchen (in prep.)

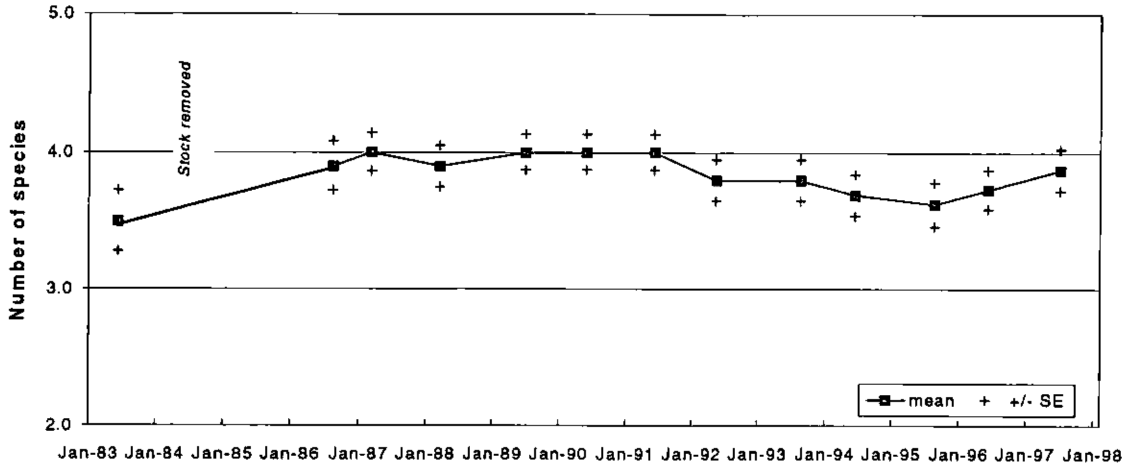
Figure 3.6 Dominance changes in major plant species following release from grazing, West Finniss





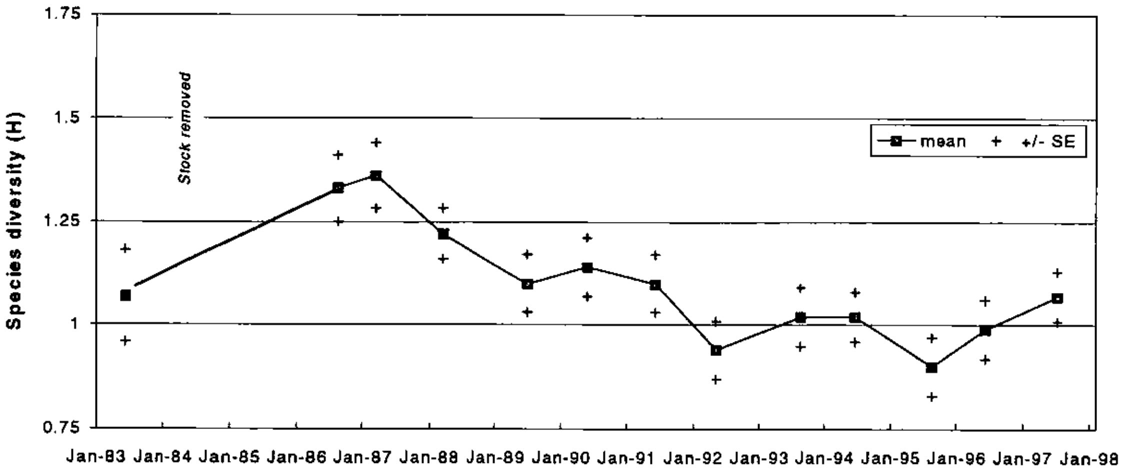
Source: Fatchen and Fatchen (1993)

Figure 3.7 Lack of change in mean species richness on vents and tails following release from grazing, West Finniss



Sources: Fatchen and Fatchen (1993); WMC (Olympic Dam Corporation) database; Fatchen and Fatchen (in prep.)

Figure 3.8 Changes in plant species diversity (H) on springs after removal of stock, West Finniss



Sources: Fatchen and Fatchen (1993); WMC (Olympic Dam Corporation) database; Fatchen and Fatchen (in prep.)

Fenced springs examples

Equivalent outcomes of protection from stock are evident from the photographic monitoring for DEHAA-fenced springs (Appendices), and were noted in Harris (1992). There have been demonstrable shifts to a high biomass/low diversity/reduced water state in:

- Old Nilpinna (Appendix E)
- Big Cadna-Owie (Appendix F)
- Big Perry (Appendix G)
- Tarlton (Appendix H)
- The Fountain (Appendix I)
- Outside (Appendix J)
- Twelve Mile (Appendix K)

Coward (Appendix L) is in early transition, equivalent to the early stages of changes at West Finniss. Leaving aside Strangways, where water quality probably prevents the establishment of *Phragmites* and *Typha,* only Blanche Cup and The Bubbler, both low-diversity springs to begin with, have not followed the shift to increased biomass. However, with the single exception of the Little Bubbler, other vents in the Wabma Kadarbu reserve are shifting to high biomass/low wetness states, in all cases with the development of *Phragmites* stands.

3.3.3 Influence of group size on outcomes of stock removal

Removal of stock is always accompanied by an increase in plant biomass and at least some decrease in apparent wetness. The most common specific outcome is the dominance of *Phragmites australis* (carbonated waters) or *Typha domingensis* (sulphated waters) at high biomass, as in the preceding examples, with all the associated implications of reduced diversity and major flow reductions. Other outcomes are possible, Blanche Cup and The Bubbler providing examples, but much less likely.

In the very large spring groups about Hermit Hill, some springs still remain dominated by species other than *P. australis* or *Baumea juncea,* and there exist cases of very high diversity mounds, still wet, with every local spring species still represented on them (Fatchen and Fatchen 1993). The continued presence of these outcomes contributes significantly to the high diversity of the groups.

The point however is that such outcomes are less likely to occur than the most probable outcome. In a very large spring group, very low probability outcomes of release from stocking will be found somewhere, simply because the number of opportunities (vents) is high (for example, some 400+ vents along the Finniss Creek course in Old Woman, Old Finniss and Hermit Springs spring groups: Kinhill Stearns 1984). Opportunities for low probability outcomes are increased by the presence of other disturbing factors, particularly flooding, which affect springs unevenly. In West Finniss spring group, still large at 50-60 vents, there is less chance of observing a low probability outcome for reason of fewer opportunities alone, further reduced by the absence of disturbing factors such as floods (Fatchen and Fatchen in prep,). In the handful of vents included in the spring fencing program, low probability outcomes such as a failure of *Phragmites* to colonise and a maximisation of free water might be desired, but are unlikely to occur given the limited opportunities (Appendix N).

If management objectives both require the removal of stock and aim for low probability ecological outcomes, they will only be achieved passively in large groups of springs, and only then in a minority of cases. In small groups, active manipulation becomes necessary.

3.4 Flood and fire influences

3.4.1 *Flood*

Floods as a recurring catastrophic influence have been mentioned in Section 2.2.4. Springs do not have to be in the main course of a stream to be occasionally swept by flood. Buttercup Spring is an isolated mound on the edge of gibber downs. It adjoins but is some metres above the floodplain of Margaret Creek, itself some 2km wide between Buttercup and the tall travertine mound at Mt Hamilton Station ruins. In March 1989, hydraulic damming of Margaret Creek between Mt Hamilton Station ruins and Buttercup Spring resulted in floodwaters leaving the floodplain, and actually cresting local gibber ridges, and in the process reaching to within less than 1m of the top of the Buttercup mound (TJ Fatchen personal data). Flash flooding in normally dry broad washes on Hermit Hill planed the vegetation from springs on the high terraces of Finniss Creek, which were out of reach of the actual Finniss Creek floodwaters (Fatchen and Fatchen 1993).

3.4.2 *Fire*

Fatchen and Fatchen (1993) suggested fire as a mechanism whereby species severely disadvantaged by *Phragmites* dominance, particularly *Eriocaulon carsonii,* could maintain populations prior to the introduction of local stock. Pastoral workers used fire to clear vegetation, primarily *Phragmites australis* and *Typha domingensis,* on Emerald Spring in summer 1987/88. The fire incidentally damaged the fence which had permitted the establishment of dense vegetation, but stock pressures did not significantly impact the spring until after June 1990. The initial response (Figure 3.9) was a rapid increase in the opportunistic species *Cyperus laevigatus,* dominating the spring in 1989, and regrowth of *Typha* domingensis, dominating the spring in 1990. *Phragmites* had shown no sign of recovery. Subsequent stock effects, including the influence of fence repairs and further breaks, were as predicted from the conceptual models.

The significance of the observations was that burning suppressed both *Phragmites* and *Typha* long enough for an opportunistic species to expand from relatively low levels to dominance, albeit temporary. On this basis, Fatchen and Fatchen (1993) proposed experimental firing of *Phragmites*-dominated mounds in Hermit Springs, to test their prediction that re-colonisation of *Eriocaulon carsonii* would be expected. One natural wildfire on a vent dominated by dense *Cyperus laevigatus* had already been recorded, with charring of the vent's marker peg indicating an explosive combustion: eg lightning strike or possibly spontaneous combustion of marsh gas (Fatchen and Fatchen 1993).

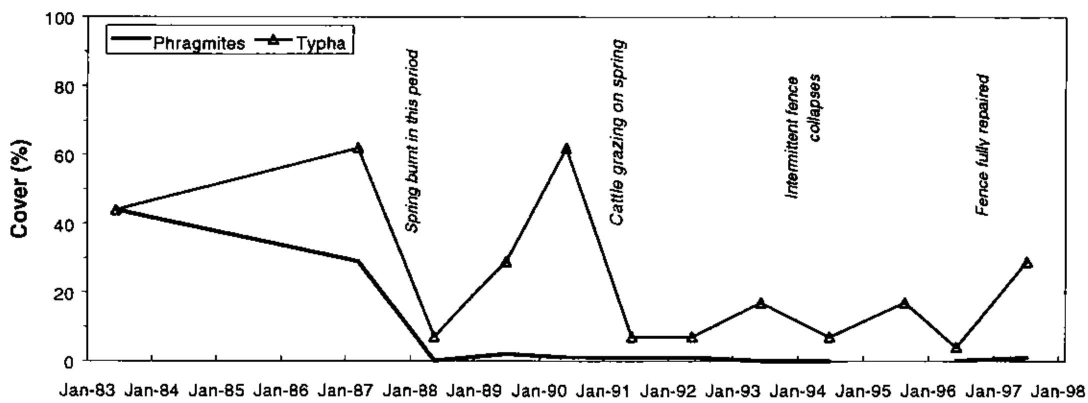
A wildfire occurred at some point between winter 1993 and winter 1994 in two contiguous mounds in Hermit Springs. The date, time and cause was unknown, though the pattern of burning indicated that the fire started in the center of the mound, and incomplete combustion of *Phragmites* on the mound indicated it to have been during *Phragmites* growth in summer, both suggestive of lightning strike (Fatchen and Fatchen in prep.). Reed heights prior to the fire were above 5m. In 1983, under heavy stocking, the mound was wet, and dominated by *Eriocaulon carsonii* (Figure 3.10). Following removal of stock, *Phragmites* growth had resulted in an eventual local extinction of *Eriocaulon*, first displaced by competitive exclusion to the mound periphery, and then lost as the periphery dried out. Following the burning, the mound was wetter, and *Eriocaulon* reappeared between 6 and 18 months or so following the fire (Figure 3.10). Occurrences were on the intensively burnt portions of the interior of the mound, not the periphery.

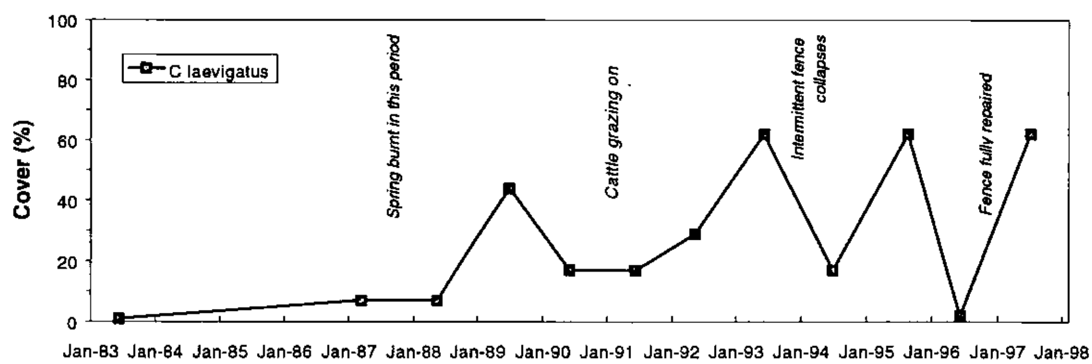
It is emphasised that the performance of this mound post-burning was predicted by the spring dynamics models *before* the event. The fire was, in effect, an experimental test of the already existing hypotheses regarding fire as an appropriate mechanism for manipulation.

One limitation on the use of fire as a management tool is the possible deleterious effects on aquatic fauna. The hydrobiid *Fonscochlea accepta* species known to be present on Emerald Springs prior to the fire can no longer be found (D. Niejalke pers. comm.). As the firing took place at a time when the spring tail had been severely pugged and stripped of vegetation by intense cattle pressure, there may have been no source of recolonisation following burning. Unfortunately, the Hermit Springs mounds burnt 1993/1994 were not among those monitored for aquatic fauna, and hence the fire could provide no insight.

Figure 3.9 Cover responses to burning at Emerald Spring

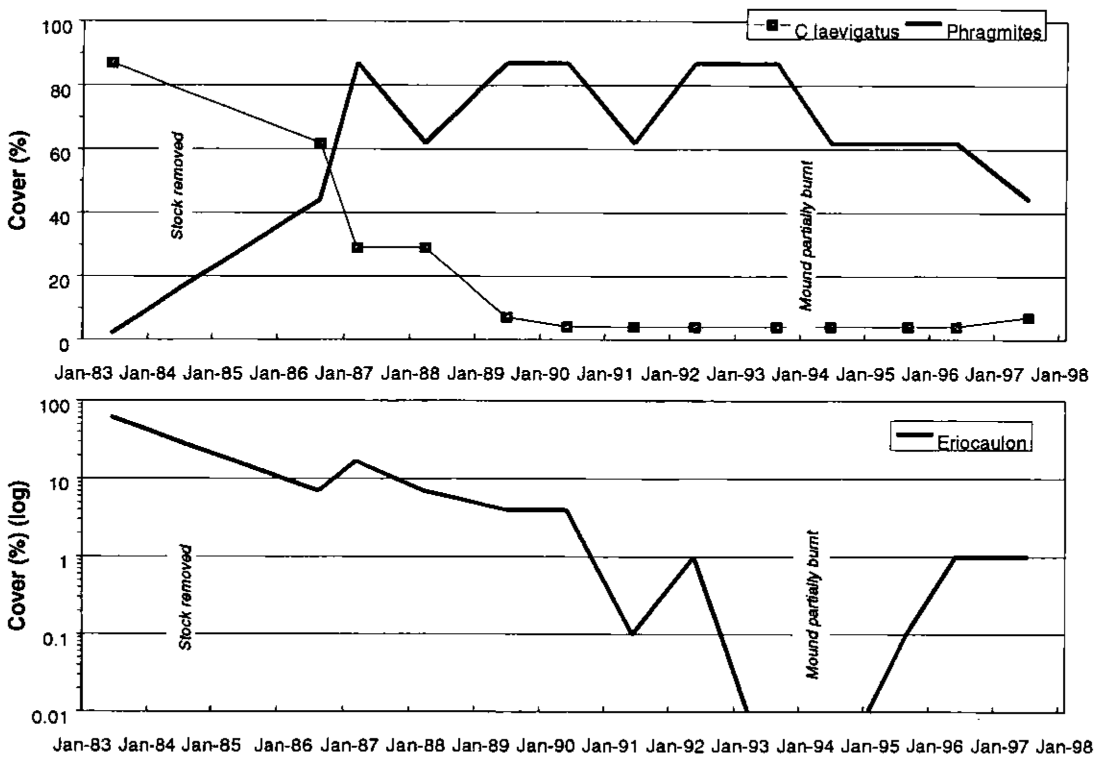
Cover values are Domin Scale midpoints





Sources: Fatchen and Fatchen (1993); WMC (Olympic Dam Corporation) database; Fatchen and Fatchen (in prep.)

Figure 3.10 Response to stock removal and subsequent burning in Hermit Springs (spring HHS172)



Sources: Fatchen and Fatchen (1993); WMC (Olympic Dam Corporation) database; TJ Fatchen

3.5 Very long-term changes following exclusion of stocking

Within the intensively-monitored spring groups on the former Finniss Springs station, there are few indications of long-term changes. In particular, there is still no evidence for a predictable deterministic plant succession, and much evidence for stochastic processes involving random colonisation/extinction and responses to intermittent disturbance. In the Finniss Creek course, there has been an increase in the small trees *Acacia salicina* and *Myoporum acuminatum*, distributed by flooding. Elsewhere, there appears to have been a slow increase in cutting grass *Gahnia trifida.* However, apparent diebacks of both *Phragmites australis* and *Baumea juncea* have been followed by regrowth in later years. With minor perturbations, the springs appear to have reached and to be maintaining a dynamic equilibrium in which oscillations occur without any long-term trend in operation.

It is always possible that the general domination of *Phragmites* or *Typha* is a transient phenomenon on a timescale of several decades. It would seem more likely, given the dynamics observed since 1983, that it is not transient, or at best is part of an oscillating system. The flood-sectioned spring in Figure 2.5 is currently a *Phragmites*-dominated mound. The alternating layers of silt and peaty material strongly suggest that it has been stripped of whatever species was dominating several times in the past, taking the oscillation to prior to European occupation.

4. MANAGEMENT FOR WHAT PURPOSE?

4.1 Plural characteristics, singular approach

There exist neither archetypal springs, nor archetypal spring groups (Section 2). There is a significant range and variety in multiple physical and biological dimensions: flow rates, water chemistry, mound building, group size and compactness, peculiarities of location, spring-dependent plants and animals, endemic and relict species, all interacting. There are associated cultural, mythological and heritage/historical values, varying from place to place.

There is an acceptance that the biological and genetic diversity of the springs should not be lost. This has dominated all approaches and largely determined the general intent of both conservation initiatives and industrial impact mitigation. Impact mitigation has revolved around minimising GAB supply and pressure changes potentially affecting springs, an essentially passive approach. The main management approach urged and attempted in conservation initiatives has been the protection of springs from domestic grazing, either by inclusion within the reserve system or by direct fencing of individual springs and groups. This is, in effect, the application of a single management tool to a wide range of variability and for a multiplicity of purposes. In light of both the variation across springs, and the observed biological dynamics, its appropriateness must be questioned.

4.2 Original purposes and actual outcomes of spring conservation initiatives

4.2.1 Real intentions and absent objectives

The existing spring fencing program arose from SA Government undertakings for inclusion of the most important of the springs in the national park system, with protection by fencing for a range of others (Harris 1992).

The proclaimed intention was protection of the springs, mainly from grazing, on the view, universal at the time, that grazing necessarily degraded springs (Casperson 1979; Harris 1981; authors in Greenslade et al. 1985; Kinhill Stearns 1984 and supporting documents; Ponder 1986).

The implicit assumption, as in the case of much reservation for biological conservation processes, was that with the removal of domestic stock, "natural" processes would proceed unaffected by the alien pressures stock imposed. Explicit objectives, in terms of what end state was actually being sought, or what the desirable state might be, were not set.

The reservation of the whole of Dalhousie Springs within the much larger Witjira National Park aside, the limited resources available for fencing were initially directed to the protection of *individual* springs. These were defined by a prioritisation which, even at the time, was not wholly satisfactory.

4.2.2 Limitations of early priorities

Conservation priorities were established largely from the biological assessment of Social and Ecological Assessment (1984), modified with some reference to cultural heritage and physical variability but with only limited input derived from the springs being examined as part of the Olympic Dam environmental assessment (Harris 1992). Biological conservation priorities were based on:

- Species diversity (primarily species richness) of both plants and animals,
- Rarity status of plant and animal species,

- Spring condition ("naturalness"), and
- Perceived vulnerability to damage.

Most of these parameters are descriptors of *states* at a given time, not *processes* changing with time. Especially, "naturalness" and perceived vulnerability are both perceptions which, in grazed springs, will very much depend on whether stock are present (drought) or absent (growth periods). Processes were not taken into account. Indeed, the notion of springs being highly dynamic biological systems was not well regarded at the time, nor was it self-evident given the tendency of stocking to maintain a single dynamic equilibrium.

Also, although springs were recognised to be "islands" of a sort, very little emphasis was given to questions of island biogeography, particularly how many islands (individual wetlands) within an archipelago (spring group), and the consequences. Isolated springs were, however, recognised as being much more prone to perceived and actual stock damage than springs in larger groups, and this tended to direct emphasis toward individual springs.

The emphasis on individual springs was further compounded by the requirement to consider protection in terms of exclusion of stock: the form management was to take in effect directed how priorities would be determined. Hence, the large Hawker, Francis Swamp and Billa Kalina groups were regarded as having a high priority for protection, but were omitted from the final prioritisation because of the perceived difficulty in fencing them, as well as perceived low levels of impact from stock.

Generally similar parameters were also considered in ranking the conservation significance of spring groups, and stating significance of impacts, in the WMC-commissioned studies summarised in Kinhill Stearns (1984). The evaluation differed from the preceding, however, in:

- Emphasising island biogeographic processes actually in operation
- Emphasising the importance of group size in species diversity, rather than individual springs
- Indicating the likelihood of springs being highly dynamic on an ecological rather than geological timescale, and the absence of any deterministic ecological succession.

Therefore, the outcomes of the two attempts at priorities were considerably at variance with each other (Table 4.1). Although there was a degree of overlap, the Kinhill Stearns listing had a bias toward large spring groups. The priority spring list used as the base for spring conservation initiatives, particularly the fencing program, had a bias toward small groups and individual springs.

The biases influenced both conservation initiatives and views on significance of impacts. Impact evaluations were most concerned with avoiding or mitigating impacts on large groups, perceived to possess in quantity the major attributes, and states, deserving protection. The actual fencing program commenced protecting single springs, or mounds with a handful of vents, seen to possess attributes most at risk. (The effective exclusion of stock from Finniss Springs station was happenstance, not design. The destocked station was subsequently acquired, originally for future reservation within the National Park system (Harris 1992), but is now earmarked as Aboriginal land, which does not preclude restocking.)

4.2.3 *Objectives of the initial fencing program as defined by outcomes*

Representativeness objectives

In terms of the representation of variability within the fencing program, the prioritisation process resulted in a skewed application of limited resources. As defined by outcomes, the *de facto* objective has been the application of fencing to individual spring vents (though not always their full outflow tails), of strong flow, on large mounds. Dalhousie Springs aside, only isolated springs or small groups are represented. Given the variation outlined in Section 2, it can be forcefully argued that the fencing program is not at all representative.

Table 4.1 Contrasting views of conservation significance, 1984

Spring or spring group*	"Priority" spring or group cited in Harris (1992), derived from SEA (1984)	Conservation significance of groups in Kinhill Engineers (1984)	Approx. vents in group	Fencing program
Hermit Springs	X	X	200	
Old Finniss Springs (incl. Old Woman)	X	X	100 -150	
Hawker Springs		X	60-70	
West Finniss Springs	X	X	50	
Francis Swamp		X	40-50	
Freeling Springs (Peake Ruins)	X	X	20-30	
Billa Kalina		X	30	
Davenport Springs	X	X	20	
Welcome		X	15	
Strangways (Telegraph Reserve) Springs	X	X	?10	X
Bopeechee Springs	X	X	10	
Twelve Springs (east of Marree)	X		?10	
Twelve Mile Springs	X		8	X
Blanche Cup spring group	X	X	6	X
Old Nilpinna Springs	X		3	X
Big Perry Springs	X		3	X
The Fountain Spring	X		1	X
Coward Spring	X		1	X
Big Cadna-Owie	X	X	1	X

*Dalhousie Springs excluded from comparison.

Biological conservation objectives

The *de facto* biological conservation objective of most fenced springs, as defined by the outcome, has been *the maximisation of wetland plant biomass.* This outcome is generally accompanied by:

- reduced plant diversity, though not necessarily richness,
- reduced total wetland area, although the area actually vegetated may be increased,
- reduced wetness, sometimes involving a total loss of free water on the surface, and
- reduction or loss of aquatic fauna.

From Section 3, stocking tends to maintain a dynamic equilibrium involving low biomass, moderate diversity, low cover, open water, and scope for local invasions and abundance shifts. Exclusion of stock usually leads to another dynamic equilibrium involving dominance shifts leading to decreased diversity, increased biomass, increased transpiration and some sealing of vents, reduced free water, a squeezing out of less competitive plants (with a temporary increase in diversity at the changeover point) and usually a "win" for *Phragmites* or *Typha,* less frequently other species.

Spring-dependent endemic species with poor dispersal characteristics, particularly the hydrobiid snails but also the endemic plant *Eriocaulon carsonii* may be put at serious risk in two respects.

First, expansion of dense vegetation may force them to spring peripheries or into tails. These are marginal habitats: they pose inherently higher risks from external agents and water supply fluctuations. Second, the marginalised species are at risk of surface water disappearing, even temporarily, due to increased transpiration demand and vent blocking.

Other long-term outcomes are possible, but of much lower probability given the dynamics of springs. Lower-probability outcomes, by definition are unlikely to appear where opportunities are few.

One particular variation in outcome should be noted, that for Outside Springs (Appendix J). While the fenced spring shifted to the high-biomass/low-diversity state, its immediate neighbour remained under stock in the low-biomass/high-diversity state. Because of the proximity of the two vents, the diversity of the local group, however defined, is actually enhanced.

4.2.4 Subsequent changes in emphasis

The most common biological outcomes are all clearly predictable for the reasons detailed in Section 3. The possibilities of such outcomes were raised at the time fencing was contemplated (Kinhill Stearns 1984), and became demonstrable within a very short time on the springs first fenced (Appendices). As well, Ponder (1986) had been urging consideration of biogeographical processes in protection, rather than an emphasis on individual springs. Responding to both aspects, the emphasis in the fencing program shifted to protecting whole wetlands (as at Coward, Appendix L).

Prioritisations based on skewed representativeness did not change, nor did the explicit focus equating exclusion of stock to protection of springs.

Subsequently, a model of protection based on selective reservation of archipelagoes of springs has been applied in the Wabma Kadarbu Mound Springs Conservation Park (foreshadowed in Harris 1992). Stock exclusion in 1995 has resulted in the high-probability biological outcome occurring in most of its vents, though not in the previously-fenced Blanche Cup and Bubbler springs, nor in the previously unfenced Little Bubbler. However, the reservation of the spring group, rather than the exclusion of stock from single springs, increases the opportunities for low-probability outcomes. Similarly, the main group of springs at Strangways was fenced in 1996. At present, there are options for extending fencing from Wabma Kadarbu to include other whole groups, fencing of the Kewson Hill-Elizabeth-Jersey archipelago, and excluding stock from the large Francis Swamp spring group.

4.3 One or multiple outcomes?

4.3.1 All things are possible, but not all at once

It is clear that stock maintain a particular dynamic balance, and that their exclusion results in a shift to another balance, tending to maximisation of plant biomass at the expense of plant diversity, water availability, and much of the aquatic fauna. "Protection", explicitly directed at stock exclusion, does not and cannot be translated into actual management objectives. The conceptual models (Section 3) indicate mechanisms for:

- maximising vegetation diversity,
- maximising plant biomass,
- maximising survival of endemic and relict plants,
- maximising habitats for mesofauna,
- maximising availability of free water,
- maximising vegetated wetland area;

but *not all in one place at one time*. The possibilities are either mutually exclusive or nearly so at the scale of a single spring or small spring group:

- maximising vegetation diversity requires regular perturbation to keep the spring community in a transitional state, preventing maximisation of biomass
- maximising plant biomass requires protection from perturbation to permit the development of dense reed, rush or other growth, preventing maximisation of diversity
- maximising survival of endemic and relict plants is species dependent. Two of many examples:
    - maximising *Eriocaulon carsonii* requires suppression not only of *Phragmites,* but also *Baumea juncea* by regular disturbance
    - maximising *Baumea juncea* requires protection from disturbance, in the process suppressing *Eriocaulon*
- maximising the aquatic mesofauna habitat is also species-dependent. Hydrobiids may require disturbance to reduce plant biomass and avoid populations being displaced to marginal habitat; in the process, other spring-dependent groups, such as endemic spiders requiring dense vegetation, may be disadvantaged
- maximising free water requires minimisation of plant biomass.

With or without stocking influences, most can be achieved somewhere within a large spring group, where a variety of natural disturbance processes and a variety of colonisation opportunities are present. The superposition of stocking will then influence which outcomes will be most common. The smaller the spring group, the fewer that can be achieved without the introduction of active manipulation: stock may lead to the elimination of some states, absence of stock to the elimination of others. Multiple states cannot be simultaneously achieved in a single spring.

4.3.2 An active choice is needed

Which outcome is wanted, where and when? There is no simple answer, and no single answer. Yet an active choice is necessary, otherwise the *de facto* objective of spring protection remains the highest probability outcome, the maximisation of plant biomass and its consequent effects. Even in very large spring groups, where low-probability outcomes can be expected to occur somewhere, they will still be minority outcomes. It must also be recognised that the highest probability outcome *itself* should not be dismissed in setting management objectives.

If multiple outcomes are sought, they will necessarily require a multiple of situations in which to occur, and a multiple of approaches to achieve them.

Well-intentioned but vague general aims such as "maintaining biodiversity" or "protecting the springs" do not automatically translate into management objectives. Objectives need to be specific, translatable into management actions (or inaction, itself a choice), achievable, and testable.

"Protecting the springs" can be translated into the very specific objective of excluding stock and people. In most locations, the ecological dynamics of springs will ensure a shift to high biomass, accompanied by reduced plant diversity, reduced wetland area and reduction or loss of aquatic fauna. Present evidence does not indicate any very long-term alteration to this outcome.

Low probability outcomes of passive protection will only appear where sufficient opportunities exist -- in groups with numerous springs -- and even there dependent on the intensity of natural disturbance. If other outcomes are desired, then other manipulations will be necessary to achieve them.

The plurality of mound springs distributions and characteristics requires a plurality of objectives and management approaches, in a plurality of locations. Altogether, a change is needed in the paradigm of spring protection and manipulation.

5. STRATEGIC APPROACHES TO SPRING MANAGEMENT

5.1 Changing the spring management paradigm

5.1.1 Accepting springs as dynamic entities

To make any sense of future spring management and conservation, there must be a paradigm shift. The first and most critical shift is from a biologically static view of springs to a biologically and physically dynamic view, with dynamics operating on short as well as long time scales. The dynamic view has influenced the later fencing programs

5.1.2 Accepting manipulation for desired outcomes

The second shift needs to be away from the view, implied or explicit, that any manipulation of springs is an unnatural activity, to be avoided or prevented wherever possible. Natural sources of disturbance exist -- fire, flood, even the appearance of new springs and the disappearance of old -- and the weight of evidence indicates long-term human manipulation by artificially lit fire as well.

Stock as manipulative agents

Stocking needs to be regarded as a major manipulative treatment of springs, rather than intrinsically, or automatically, damaging to all spring values. Detriment or benefit can then be judged depending on the outcome sought, rather than on the agent used to reach that outcome.

Stocking involves several species of introduced ungulates, and as such, can be viewed as an alien influence (in contrast to natural disturbance and pre-European use of fire). In the study area, cattle are dominant but the disturbance processes are known to be similar for sheep, feral horses and donkeys. Grazing by native species does not appear to be an issue outside the Dog Fence: it is now generally accepted that native grazers under dingo predation were at similar low levels prior to European settlement as today. One might query, though, whether this was the case when the Pleistocene megafauna were utilising the springs.

All springs have stocking pressure, whether domestic stock are excluded or not -- from feral grazers, from intermittent fence failures, from normal domestic stocking. The *fact* of stocking is immaterial. It is the *intensity* of stocking which will strongly influence the ecological processes operating in spring wetlands, and the state of the systems at any given time.

Intense stocking on a single spring may well, on that spring, act to the detriment of all the biological processes and characteristics currently judged to be valuable. If the spring is isolated, the detriment may be permanent. If the spring is one of many in a compact group with varying intensities of stocking, the creation of invasion opportunities might *enhance* the characteristics judged valuable for the group as a whole. The outcome depends on the context.

Fire and other manipulative agents

Fire is a simply applied manipulation, for which a predictive model exists, albeit primitive, and for which there is evidence of pre-European use. As with stock, how and when fire is applied, and at what intensity, may well control outcomes. Further experimental and ethnographical investigation is needed. Fire has the management advantage that its use as a manipulative tool can be applied selectively, at a particular point in time, under direct control, which is not the case for stock.

Other manipulative tools are available, for example physical cutting of dense vegetation and break-up of caps to increase local wetness. Another manipulation which we have not discussed, but which should be at least raised here, is direct manipulation of local aquifer pressures as an active rather than passive influence. A short re-injection into the GAB was successfully applied locally to Bopeechee Springs, to stop a flow decline in the spring group resulting from regional drawdown (WMC (Olympic Dam Corporation) 1998). *Increasing* spring flows by local reinjection into the aquifer is a logical corollary, and technically feasible.

5.1.3 Increased emphasis on protection of non-renewable resources

A further shift is needed in emphasis. In almost all approaches to conservation of mound springs, physical characteristics have been secondary to biological characteristics. Hence, emphasis in protection has been toward maintaining endemic species, or "protecting" biodiversity (however defined). But the biological attributes are at least potentially renewable, whereas many of the physical attributes are not. Disintegration of limestone terraces, breaking of carbonate mounds, the muddling of the recent stratigraphic record and the muddling of the archaeological record are all irretrievable.

Physical features may thus present a strong case for limiting stock, and other trampling impacts, regardless of consequences for biological outcomes. If the second shift to accepting the validity of manipulation has actually been made, then the biological outcomes consequent on exclusion can be manipulated to the state desired in any case.

An illustration is provided in current options for stock exclusion in the immediate future. The Francis Swamp group, groups within reach of an expanded Wabma Kadarbu park, and the Kewson Hill - Elizabeth spring archipelago are all available for stock exclusion. Springs in the latter two areas possess very significant geomorphological features which are non-renewable, susceptible to trampling damage, with cumulative damage observed.

Specific examples in possible Wabma Kadarbu extensions are the graded series of conical carbonate mounds at Horse Springs (east). Here, progressive breaking of caps and crumbling of mound slopes has been consistently recorded over the course of Olympic Dam-related monitoring. The Kewson Hill - Elizabeth block includes areas of small terraces, easily damaged. The word "fragile", best avoided in discussions of ecological dynamics, is appropriate to these physical characteristics. In both areas, springs also tend to be either isolated, or in very small groups, intensifying the actuality of damage.

Stock exclusion here is necessary to protect the formations alone, even though the (un-manipulated) biological outcome in most springs will be strong reed growth and its consequences. It can also be rationally argued that fencing in these groups should precede fencing in the biologically more significant Francis Swamp group, where the existing impact of stock is diffused through a large number of springs, relatively compactly arranged, and lacking the non-renewable features of the preceding,

5.1.4 Application

The changed paradigm neither negates the need for exclusion of stock as an important manipulation in spring management, nor does away with the present fencing program. The majority of springs are stocked; intensive stock pressure does operate to the detriment of many biological groups; isolated springs and small groups are most likely to suffer intensive pressure; and there does not yet exist, for other biological groups, the level of information available on vegetation.

Indeed, it is clear that much more stock exclusion should be undertaken, both to increase the representativeness of the spring sample not subject to stock, and to increase the proportion of unstocked springs. Even were the current fencing programs expanded tenfold, stock would *still* be the main factor manipulating the majority of springs. This alone is a cogent argument for not only continuing, but also expanding the fencing programs.

There is, however, a shift in emphasis. Overall, we are seeking a diversity of outcomes in a representative spread of springs. The diversity of outcomes cannot be achieved under stocking, nor by stock exclusion, nor by the two together.

Additional manipulation in unstocked situations can expand the feasible outcomes, but there have to be unstocked situations to manipulate in the first place. Dense reed growth, the highest-probability outcome of stock exclusion, will be detrimental to some biological groups but may positively advantage others, for example endemic spiders. Why should the most probable outcome of protection from stocking *not* also be one of the diversity of outcomes sought?

5.1.5 Future strategies and immediate actions

The whole strategy of spring conservation clearly needs to be developed further. Questions of representativeness must be resolved, a multiplicity of objectives need to be set, means of achieving them worked out and the locations in which to achieve them determined. This is not something that can be achieved in the confines of this report, but a start can be made via the already fenced springs.

In advance of detailed objectives, *maximising the diversity of outcomes* would appear to be one rational interim aim. Management recommendations for the fenced springs in this report are primarily aimed at doing so in the limited spatial and temporal opportunities they provide (Section 6; Appendices). The fact that only limited opportunities exist points to another obvious aim, improving the representativeness and replication of springs with stock exclusion.

Thus there need not be a continuation of the "policy vacuum" identified by Harris (1992) while waiting for the outcome of future investigation and synthesis. Enough information already exists to recast approaches for setting priorities, to indicate where more options for increasing diversity can be pursued, and to improving representativeness of the springs not subject to domestic stocking treatment.

5.1.6 Future advances in understanding

The 1998 mound spring researchers' workshop in Adelaide (Niejalke 1998) produced a consensus on the current state of understanding of mound spring function, and recommendations for future research and management. Emphasis in the workshop tended to biological aspects of the springs, inevitably reflected in many of the recommendations (provided in full in Appendix N), which does not negate their importance. Needs were perceived for investigations into:

- influences of dense spring vegetation on distribution and abundance of other spring-dependent biological groups;
- effectiveness of alternative manipulations of spring vegetation;
- genetic and ecological questions ;
- lesser-known biological groups, particularly where there may be significant endemism;

all of which will influence the detail of how springs are managed and what outcomes are desired.

These and other recommendations, and the consensus on the level of understanding of spring systems, emphasise that the springs are still full of unknowns. The current level of understanding may change as radically over the next decade as it has over the past. Such a possibility provides further reason for attempting to maximise the diversity of outcomes in spring management. Some of the outcomes may prove eventually to be unwanted and undesirable, but the preferred outcomes should be represented as well.

5.2 Developing the information base

5.2.1 Improving baseline information

Biological

Management of springs has been limited by a piecemeal approach and uneven application of investigative resources. There is far more information now available than in the early 1980s, when industrial and mining development brought the springs into a new, and urgent, focus; but its distribution and quality is very uneven.

In terms of an information baseline, we remain heavily dependent on the early 1980s survey material outside the areas covered in investigations and monitoring to do with the Olympic Dam development. In the latter, statutory requirements for environmental monitoring and voluntarily extended environmental work by and at the expense of WMC and subsidiaries has produced a dense data set, without which the ecological models applied to management in this report could not have been derived. Their sponsoring of spring research as part of the Lake Eyre South Study (Royal Geographical Society of Australasia, SA Branch) should expand part of the data set over a wider geographical range, particularly as regards endemic aquatic fauna and habitat relationships, but still not over the whole south-western arc.

Over the rest of the springs, the baseline is still effectively that provided by Social and Ecological Assessment (1984). It can be modified and updated in several respects, particularly the incorporation of advances in knowledge of evolutionary and biogeographical aspects of the fauna. However, in terms of management and monitoring of management, it does not provide a baseline in three critical aspects:

- the number and compactness of active springs,
- apparent flow, whether in terms of vegetated area or a wetness score, or an actual measure, and
- the state(s) of spring vegetation, in terms of actual and relative abundance.

The fenced springs (Appendices) demonstrate, case by case, the limitations imposed where the baseline information does not provide some "hard" data on actual and relative abundance of plants, or on flow attributes at the time. Photographs are limited in the degree to which they can be interpreted.

In view of the dynamics now demonstrated, there is a strong case for re-visiting the full spectrum of springs and re-establishing baselines for these aspects. For maximum comparability, rapid survey as applied in vegetation baselines and monitoring for the Olympic Dam environmental work is suggested, since to date this has been the only management-oriented biological monitoring methodology demonstrably able to integrate information, erect and test hypotheses and provide a working predictive model.

Physical

Non-renewable resources, readily and permanently damaged by stock (or people) have been emphasised. In terms of geological and geomorphological characteristics, there has been no attempt at synthetic description of the range and variety throughout the springs, nor an assessment of the representativeness or significance of the features. There would appear to be enough information available piecemeal, within the physical literature generally (eg references in Boyd 1990) or in personal knowledge (eg Habermehl pers. com. in Niejalke 1998). Such a synthesis needs to be undertaken.

Evidence of climatic change potentially held in spring sediments has been cited earlier as a major reason for concern over physical damage by stock. Apart from the pollen analyses of Boyd (1994) at Dalhousie, we know of no other work in this direction. It presents a major gap in the spring information baseline.

Social and cultural

The emphasis on the biophysical aspects of mound springs has tended to obscure cultural values. The present report itself reflects this emphasis. A synthesis is needed of cultural aspects which can be translated to specific objectives associated with specific springs. The body of inventory of Aboriginal archaeology and anthropology is now considerable (Lampert and Hughes 1985, Lampert 1985, 1989; Hercus and Sutton 1985) but the practical problems of incorporating what is known into on-ground management objectives remain as stated by Harris (1992, p168). Aspects of Aboriginal cultural heritage, which should strongly affect the emphasis on local objectives for a spring or spring group are, by their nature, not freely available. They cannot be explicitly and publicly factored in as part of a prioritisation, and their overt protection may simply draw public attention to them. The best resolution of the conundrum would appear to be a greater degree of consultation between the biophysical and the cultural investigators, and a much greater degree of co-operative work in the development of specific management objectives for each area.

Geographical spread

The limitation of effort in spring management to springs west of Marree arose due to pressures associated with the Olympic Dam project water requirements, rapidly increasing visitation along the Oodnadatta Track and at Dalhousie, and pastoral use pressures. However, the springs east of Marree need to be re-incorporated into strategic planning within the State. Their baseline information is very limited in all respects. The further extension, of course, is the application of the principles throughout the margins of the GAB.

5.2.2 Improving monitoring

Outside the area monitored as part of the Olympic Dam programs, there is very limited monitoring of spring changes, and that only applied to the fenced springs. There is no monitoring information available, and hence no present ability to assess changes, for major groups such as Francis Swamp, Hawker Springs, Billa Kalina, let alone small groups such as Levi. The problem is compounded where there is no baseline to monitor from, as in many of the minor groups.

Monitoring in some form is essential as feedback to management: no matter how good the predictive model, the actual management outcome needs to be checked -- indeed, the sooner the better if the model has flaws -- and management altered accordingly.

In the DEHAA-fenced springs, only the photographs taken provide continuity. Photographs are at least fast and observer independent. They can be used retrospectively: there are well-supported recommendations that a library of historical photographs of springs should be compiled to provide a record of change over time (Appendix N). However, photo-interpretation has limits. In brief:

- Photographs show only what can be easily seen. A shift from bore-drain sedge to bulrush dominance is obvious, but what might not be visible is whether the bore-drain sedge remains present. Cryptic plants and animals do not show up: *Eriocaulon* and hydrobiids as cases in point.
- Repeated controlled photos, taken from the same point and aimed at the same point, using the same focal length can be interpreted consistently. The less the degree of control, the less consistency possible in interpretation. Examples in Appendices have moderate control, Figure 3.4 has tight control: differences are revealing.
- "Snapshot" photographs without any control may vary so greatly that no consistent comparison over time is possible beyond "reeds have grown/not grown". In some situations, this might be all that is required, but a greater information content would be preferable.
- Photographs, of whatever standard, still have to be interpreted. This is not as straightforward or cheap as it might appear: for example, the elegant technique of Noble (1977) has been much quoted, but rarely applied (Appendices).

Remote sensing specifically directed at following gross changes in wetland areas is being explored by WMC (Olympic Dam Corporation) Pty Ltd. Such a technique, if successful and cost-effective, has potential for wide application through the spring arc. It too has limitations in picking up cryptic species, or non-cryptic species obscured by tall and dense reed cover. Remote sensing is not assisted by the propensity for many plant species, particularly grazed sedges and rushes, to present a minute vertical cross-section to the sensor.

There is thus good reason for having a "hard" data component in monitoring and not relying entirely on photographs, or remote sensing. Where ground photographs are taken, even a simple listing of main species, dominant species, an indication of relative abundance and a scaling of wetness will enhance the data yield dramatically.

The level and degree of monitoring will always be limited by the continuing and cumulative cost. Unfortunately, what is achieved tends to be directly related to the effort applied to achieve it.

5.2.3 Experimentation in active management

If maximising the diversity of outcomes is to be achieved, then some active and manipulative management will be necessary. The DEHAA-fenced springs together provide an illustrative example (Appendices). In some, reduction of reedbeds is likely to increase the likelihood of desired outcomes, in others, there appears to be no need for any active management.

There are multiple manipulation possibilities – continuous stocking, whether domestic or feral; intermittent stocking; side-by-side stocked/unstocked sequences; teams of brushcutters; and fire. Where it is desirable to avoid other impacts of stocking, fire appears to be the most effective manipulation agent, for reasons discussed in Section 5.1.2.

Experimentation is clearly required: the model of response to fire (Section 3.4.2) is derived solely from the vegetation, with no information on the aquatic fauna. Management prescriptions for the fenced springs include low-key trials for this reason, but there is a need for more intensive, and replicated, experimentation. The logical area for such experimentation is the Hermit Hill block, where by reason of impact investigations and monitoring there exists a long-term, detailed and replicated record, and where the size of spring groups allows experimentation without the risk of threatening the perceived values of the group as a whole. It is not suggested that the Hermit Hill block of spring groups require manipulation, but rather that the run of data provides long-term pre-fire information which is simply not available elsewhere. There has been no experimentation to date, not because experimentation was *per se* undesirable, but because it would have quite literally fired up further controversy associated with the Olympic Dam development.

5.3 Using the information base

5.3.1 Representativeness and prioritisation

An important recommendation from the 1998 workshop was that:

> *"the capacity to assess the economic, social and biological values of mound springs needs to be developed further so that management priorities can be established objectively"*

Source: Appendix N

Priorities in springs have been largely governed by reports from the early 1980s. The single-dimensional prioritisations of both Social and Ecological Assessment (1984) and Kinhill Stearns (1984) discussed in Section 4.2 suffer from the same deficiency: they are one-dimensional attempts to contain multi-dimensional variability. In both cases, a single ranked list was produced, dependent on value judgements which inevitably vary from viewpoint to viewpoint, and dependent on combining sometimes mutually exclusive characteristics. Both listings were almost entirely biologically based. Relative weightings of importance had to be assigned, and weightings were viewpoint-dependent. Both listings were heavily influenced by what was then known of the biology, and particularly by endemism in hydrobiid snails and by distributions of endemic and relict plants.

Even where conservation significance of particular characteristics is agreed, univariate ranking applied to multivariate and disparate values will pose problems. Figure 5.1 plots, from real data, the number of endemic hydrobiid species against the number of endemic or relict plant species in each of the spring complexes between Marree and Oodnadatta. In the upper diagram, the value judgements and priorities are already defined. On a basis of maintaining the genetic variability, the value judgement applied is that a "high" rating on either scale is of more importance than a "low" rating.

There is no way to equate the value of an endemic plant and the value of an endemic snail. Perceived importance overlaps and conflicts, defying the rational setting of management priorities (Figure 5.1, upper diagram). A single priority set, particularly when translated into a single management approach, cannot resolve the conflict. The selection of a representative subsample in which to apply the limited management resources available is arguable. The only clear outcome is that the already-set management priorities do not need to be directed to the cases where both snails and plants rate low or do not exist (group c on Figure 5.1).

The same plot can be viewed in a different way, by allowing the data to define the variation. The starting point is not the aim of maintaining the genetic variability, but simply establishing what and where the variation is. Particularly, there is no assumption of what the management action will be before the objectives are determined, and no determination of objectives without first establishing the variation. In Figure 5.1 (lower diagram), there are four clusters. There exists immediately the basis for selecting, non-intuitively, a representative sample - one from each cluster. More, the clustering itself provides some framework for setting objectives:

- objectives in group 1 need have no bearing on either set of endemics
- objectives for group 2 can be directed specifically toward snails alone without regard to the plants
- objectives for group 3 need to favour plants, but snails have to be taken into account
- group 4 needs more investigation.

Management treatments would thus involve multiple approaches, dependent on circumstance and place, and multiple outcomes.

This example is intentionally simplistic and two-dimensional, but can be extended indefinitely (Possingham in Niejalke 1998; Possingham 1997). Rather than two attributes, there can be multiple, and we can factor in quite disparate attributes: for example mound form, flow, number of springs, plant cover, actual tourist impact, self-repair capability, heritage significance, non-renewable friable carbonate terraces and the rest. Argument may still apply as to what axes are used and how they are scaled, but much less so than arguments over attempts to define priorities from a single-dimensional approach. The question is discussed at some length in the Narrative in Niejalke (1998) (Appendix N). The technique can be applied to the existing information, and adapted as new information comes to hand.

5.3.2 Continuing reservation and stock exclusion

The point is already made that the current level of exclusion of stock from springs fencing needs not only to continue, but also to expand to cover a much larger sample. Emphasis at present is on reservation or exclusion using an archipelago model, a recognition of the importance of island biogeographical processes operating at the group level. It also has the advantage of reducing fencing and maintenance costs per unit spring fenced.

In terms of maximising the diversity of outcomes, there remains a role for partial rather than whole group fencing. This is particularly so for groups, significant on any value scale, such as Hawker or the spring groups along Finniss Creek, where total exclusion through fencing is physically impossible but partial exclusion feasible. At the extreme, a return to 19th Century practice and fencing of individual springs could multiply outcomes, as at Outside, but carries the risk of closing-off alternatives, as appears to be the case at Big Cadna-Owie (Appendices).

There is a chaotic element in the revised spring management approach. While a degree of chaos is appropriate to the observed variation across the arc of springs, it does not lend itself to the development of structured hierarchies of priority, choice and action, nor to simple allocation of limited resources. On the other hand, it does provide for the intelligent application of opportunistic management as circumstances arise.

As an example, the Levi Springs area has associated high Aboriginal cultural attributes, both archaeological and ethnographic. We understand there to be strong arguments for excluding stock from part of the area for this reason alone. The springs themselves are not represented amongst existing fenced springs in the region, being small mounds of low flow. Springs are few, and intermediate in terms of compactness. There is a stock bore (Levi Bore) 1km or so distant from the nearest spring. Fencing most of the group, including the areas of cultural importance, is feasible: there are no flooding problems and partial group fencing will not impinge on pastoral activity.

In terms of their biology, the Levi Springs are undistinguished, lacking any known endemics of restricted distribution: they would not rate highly on a priority scale based on species rarity. Based on representativeness, there is little reason to exclude stock specifically from Levi rather than from the similar and nearby Milne Springs. Fencing of either would fit the aim of increased diversity of outcomes. Accordingly, the choice could be made opportunistically, to fence the area for cultural heritage protection, but also to include the springs within the fencing to increase local diversity of spring outcomes.

5.3.3 Currently identifiable priorities

The preceding subsections indicate the limitations inherent in attempting a single prioritisation and applying resources accordingly. However, the formal requirements of the present study brief require that prioritisation be attempted nevertheless. On present information, it is possible to point to groups with non-renewable resources at risk of damage west of Marree, and to groups with a multiple of biological attributes regarded as significant. This does not remove the need for longer-term development of objective prioritisation and representativeness. It does provide an interim guide to areas where fencing may be needed to halt stock-induced physical damage to non-renewable features, and to areas where there are both:

- sufficient known biological attributes to warrant increasing the diversity of outcomes by exclusion of stock; and
- sufficient numbers of springs to ensure that low-probability outcomes can still occur despite stock exclusion.

Spring structures known to be at risk

The majority of non-renewable structures potentially or actually at risk from stock physically damaging them are between Curdimurka and Strangways Repeater Station. Terraces at Strangways and the conical mound at Blanche Cup are already protected from stock. Other spring groups are:

- Anna: spring limestone caps and thin overhangs
- Mt Hamilton Station Ruins: spring limestone caps and thin overhangs
- Buttercup: silty mound edges
- Horse East and West groups: conical mounds and terraces, limestone caps and thin overhangs
- Kewson Hill: conical mounds, limestone caps and delicate terraces

- Elizabeth – Jersey area: limestone terraces.

At least the latter three can be fenced in extensions to Wabma Kadarbu Mound Springs Conservation Park. It may also be practical to include Buttercup within this fencing. Anna and Mt Hamilton Ruins are isolated by floodcourses, and fencing is unlikely to be a practical proposition.

The Freeling Springs terraces at the Peak Repeater Station ruins might also be included in this list. The list may be extended if a wide-ranging geomorphological survey were to be undertaken.

Large groups with significant biological attributes

On the various prioritisations developed by SEA (1985), Kinhill Stearns (1984), indicated in Symon (1985) and other authors in Greenslade *et al.* (1985), and applying the data summarised in Appendix M, the following spring groups have both multiple biological attributes of conservation significance, and possess sufficient vents for at least some low-probability outcomes of protection from stock to occur:

- Billa Kalina
- Francis Swamp
- Hawker
- Freeling (Peake Repeater Station Ruins)

With the exception of the last, major watercourses in the groups would prevent fencing whole groups, leaving at least some vents under stocking outcomes. Each group shows some difference in hydrogeological regime and particularly water chemistry. Whilst the groups are directly representative only of themselves, together they largely cover the range of water quality variations from beyond Strangways Repeater Station northward.

Springs on the former Finniss Springs station are assumed to remain unstocked. Were this not to be the case, to the list would be added the sequence of springs in Finniss Creek from Old Woman to Hermit Springs; the West Finniss spring group; and the extended sequence of mound, fissure and creek-bed springs at Davenport Springs.

It is likely also that the Twelve Springs/Petermorra group east of Marree should be included in this group, but the data lack the level of detail available for the preceding.

5.4 Consultation and co-operation

There are multiple users both of springs and of the GAB waters supplying the springs. Spring management requires not only consultative, but also co-operative action.

- Springs are still integral to pastoral use. There exist numerous situations where springs still supply the only water source for local stock use, and where the sinking of a bore may cause more impact on the spring than stock. Big Cadna-Owie (Appendices) is one example. Welcome and Wirringinna spring groups are others (Kinhill Engineers 1995): there are multiple examples on the extreme margins of the GAB. Pastoral industry has limited resources and manpower availability, and spring management requirements could easily affect this sector disproportionately: whatever future park or other reservation is applied, the majority of springs will still be on pastoral land.
- Water demands from mineral and petroleum development, and related industrial development must be expected to rise. Information and debate on springs has been dominated by the Olympic Dam development, but there are other possibilities for major developments with major water demand. There are extensive coalfields in the Boorthanna Trough and the Arckaringa Basin, and proposals for related industrial development at Coober Pedy.

- The springs as a whole present a remarkable ecological, biogeographical and evolutionary laboratory. The word "laboratory" is used advisedly. The relative simplicity of the biological systems in the springs, their depauperate biota and the limited niche space provided, together with their "island" distribution, provide a semi-controlled environment for scientific investigation. They have already made a major contribution to evolutionary knowledge, as distinct from information, through the hydrobiid studies of Ponder and associated researchers. Much more may emerge from current and future studies and experimentation in other faunal groups. Research is often promoted for its potential applied use, for example as a basis for specific management, but the more intangible contribution made to human knowledge as a whole must not be forgotten. In the very long term, the application of principles developed from the mound spring laboratory may extend far beyond the mound springs themselves, and far outweigh in importance the specific application of information generated to local spring management. The laboratory needs to be kept in operation.
- There are specific, present and real Aboriginal cultural associations with the springs (Sections 2.3.1, 2.4.1).
- Visitors to springs are increasing sharply. Visitation is in a somewhat different category to the preceding, in that, to the bulk of visitors, the springs may be a focus but are not central to their activities, economic survival or culture. Tourism aspects are therefore discussed separately, below.

Conservation and management approaches to springs have tended to be co-operative between Government and the first three. Avenues for co-operation are a mixture of ad hoc and formal, via a networks of consultative groups such as the Far North Consultative Committee, local Soil Conservation Boards and the SA Arid Water Resources Committee. Steering and Local Reference groups, such as those overseeing the present investigation, can be set up as needed. Other avenues are also used, as in the assistance from the mineral and petroleum sectors well beyond the statutory minimum demanded of them. The GAB Consultative Committee now provides another overlay.

5.5 Other issues

5.5.1 Land use changes at Hermit Hill

Attention is drawn to the importance, on any scale, of the large agglomeration of springs along the Finniss Creek course and tributaries near Hermit Hill. The concentration of groups, compactness and number of active spring vents is much greater than any other concentration on the southwestern GAB margin. Although originally intended for reservation within the National Park system (Harris 1992), the land is currently not reserved, and a return to domestic stocking is possible. A return to continuous domestic stocking is considered undesirable for the following reasons:

- A high diversity of outcome is maintained within the largest groups by natural disturbance and random colonisation/extinction processes. They do not need active manipulation.
- A return to domestic stocking would result in heavy pressures applied to the springs as grazing resources, not just as water sources.
- Hermit Springs contains the largest known population of *Eriocaulon carsonii*. In this spring group, *E. carsonii* has survived a habitat shift from vent centres to edges and tails consequent on expansion of other species, which initially at least halved the total population. Almost all the population is now in tails, and at risk from physical destruction. It is presumed but not certain that it would again survive the transition from tails to back to vents in the event of stock re-introduction.

5.5.2 Catering for tourism

Theme parks and hidden reserves

Harris (1982) outlined the problems associated with the increase in visitors to Dalhousie Springs following the dedication of Witjira National Park. Fencing and on-site works were necessary for protection against visitors at the well-known and always signposted Blanche Cup and Bubbler springs even before their reservation within Wabma Kadarbu Mound Spring National Park (Appendix B, C).

Generally, the usual car-associated human visitation can be considered as a discriminating form of cattle stocking. Like cattle, visitors trample and pug springs, amongst other activities; unlike cattle, visitors tend to follow signposts to springs. Even within the heavily visited Blanche Cup and Bubbler area, visitation to the unmarked Little Bubbler is uncommon. In some thirteen years of vegetation monitoring, there have only been two or three cases of evidence (footprints) of people other than those also engaged in mound spring monitoring on another spring in the immediate area. Casual visitors are rarely encountered on other springs between Marree and Blanche Cup, even where spring groups are close to the road.

Mud springs such as the majority of vents about Hermit Hill, and springs with fragile terracing, can no more withstand heavy visitor concentrations than they can heavy stock trampling. Since people are more amenable to verbal and signage direction than stock, there is a valid case for highlighting some springs as a theme park (T. Aust pers. comm.), preferably educational as well as fun, without loudly publicising the locations of the rest.

This role is currently played by Blanche Cup and The Bubbler within Wabma Kadarbu, and to a lesser extent Strangways (Telegraph Repeater Station). While a certain wilderness aesthetic may be lost by the necessary defined roads, parking lots, fences and boardwalks, nevertheless the casual visitor sees springs which are visually interesting, and learns something about the springs and their values in the process. At the same time, expensive damage-limiting resources can be applied to maximum advantage. The additional cost is nevertheless some continuing damage to the highlighted springs (Appendix B, C).

Special case of adventure/ecotourism

Low-intensity visits to springs away from the theme parks are increasing, through treks and especially camel trek operations. At present, numbers are understood to be very low. Even with major expansion, the visitation rate could be expected to remain a fraction of the car-borne visitation to springs along the Oodnadatta Track. These operations have the advantage of the visitors being largely under the control and tutelage of the operators, which is not necessarily the case in the motorised equivalents. Fencing of springs for whatever purpose may be seen as objectionable for this form of ecotourism, as a detraction from the wild country experience.

5.5.3 Invasive alien weeds or cultural heritage items?

There are several alien plant species found in the springs, proportionately a much higher level than in the surrounding arid landscape. Two species, the bamboo *Arundo donax* (properly, European canegrass), and date palm *Phoenix dactylifera*, can exclude other species and block vents, as at Birribiana Springs (bamboo) and Dalhousie Homestead ruins (date palm). A third, the tamarisk (*Tamarix aphylla)* does not appear to be invasive, but if planted can also block vents, as at former springs in Welcome, Wangianna, Beatrice and Old Finniss spring groups. They also can be viewed as important cultural relics of early settlement. The conundrum is not simply resolved. For the DEHAA-fenced springs, the management prescription has been to leave them as relics but prevent their spread, which seems appropriate as a wider management strategy also.

5.5.4 Two GAB planning issues

The brief for the present study was based on an assumption that the present supply from the GAB would continue at present levels. In terms of management of the GAB generally, this supply is an "environmental flow", for which provision is intended in the GAB Strategic Management Plan (GAB Consultative Council 1998). While whole-basin management is not within the brief, there are two points which need to be raised in relation to GAB management and the SA component of the mound spring arc.

First, mound springs in strategic or summary views tend to be treated as variations on a single theme (always excepting the Dalhousie group which, by reason of their extremely high flow, clearly stand alone). Such treatment is evident in most research sectors - hydrogeological, botanical, zoological, conservation. The standard representation of a mound spring (Section 2) uniformly pervades the literature and inevitably influences views of their biological and physical functioning. This broad view can be misleading when attempting to translate it into monitoring or management terms. There is no archetype lending itself to simple monitoring or assessment of environmental flow. The median spring is small, boggy seep of slight flow. In the arc of springs west of Marree, there appear major differences in form and many differences in function because of the mingling of waters from different recharge sources. On the limited information available, the springs about Hermit Hill may have more characteristics in common with springs far to east and northeast (eg Lake Callabonna, SA; Louth, NSW), than with the relatively close Coward complex.

Second, approaches to maintaining environmental flows have tended to be regional and passive in expression. The SA bore rehabilitation and capping has been aimed at pressure management generally. Mitigation of drawdown impact for the Olympic Dam development has revolved around avoidance of impacts where possible, and restricting them to springs with low conservation significance where not. However, the success of local re-injection to halt pressure and flow reductions at Bopeechee demonstrates that environmental flows may be maintained, and could be enhanced, by targetted, local and active measures.

6. SUMMARIES OF ISSUES AND RECOMMENDATIONS - FENCED SPRINGS

6.1 Introduction

The following summarises the issues and recommendations specifically associated with the springs of the existing DEHAA fencing program. The background, detail and rationale for each fenced spring are provided in Appendices. The recommendations are primarily governed by the following aims:

- Maximisation of habitat and ecological diversity in the absence of domestic stock, by active means where necessary
- Limitation of damage to non-renewable spring features, particularly mound formations
- Experimental demonstration of the effect of active management techniques
- Minimisation of risks inherent in trials, particularly as regards aquatic fauna
- Improvement in monitoring the outcome of management actions
- Maintenance of some biological evidence of European settlement.

6.2 Blanche Cup

6.2.1 Vegetation management

There is no reason evident for considering active vegetation management.

6.2.2 Other issues

The impact around the Blanche Cup pool could only be reduced by installing some form of boardwalk. While this might stop the infill of the pool, it would certainly detract from the visitor experience and potentially cause major problems for the spring itself. In particular, any fracture of the spring limestone could well result in development of a new tail and the lowering of the pool.

6.2.3 Management recommendations

We recommend that:

- No vegetation management be undertaken
- No action be taken to extend the existing boardwalk or to cover the rim of the pool, given the possible consequences of the necessary engineering to anchor structures
- Impacts of tourist use continue to be monitored.

6.3 The Bubbler

6.3.1 Vegetation management

There is no reason evident for considering active vegetation management. This situation may alter if *Phragmites* eventually invades the tail.

6.3.2 Management recommendations

We recommend that:

- No vegetation management be undertaken

- Impacts of tourist use continue to be monitored.
- Monitoring be expanded to cover the new subsidiary vents.

6.4 Strangways

6.4.1 Vegetation management

There is no basis for manipulative vegetation management within the group.

6.4.2 Other issues

There is a need for monitoring of springs both within and outside the larger fenced areas, particularly to establish whether the group is in fact declining. Reasons for this include both the presence of the narrow endemic hydrobiid *Fonscochlea billakalina* and the maintenance of local populations of *Gahnia trifida*.

The rare terrestrial species *Hemichroa mesembryanthemum*. Is currently being monitored by the local Soil Board. Continuation of this monitoring with the spring monitoring is suggested.

6.4.3 Management recommendations

We recommend that:

- No vegetation management be undertaken
- The current monitoring be expanded to monitor at least some of the more recently fenced springs.

6.5 Old Nilpinna

6.5.1 Vegetation management

The combination of a grazed vent/bore/wetland and an ungrazed area with less water but more biomass has, to date, resulted in a high richness spring group, with high cover diversity and high diversity in other respects, particularly the structure of the vegetation. The expansion of *Phragmites* and *Cyperus gymnocaulos* in the fenced area has stabilised, and the exotic bamboo is not significantly expanding.

Arguments for removal of bamboo and palms are:

- Both species have high transpiration rates and hence water demands. Vents may be blocked, as has occurred at the nearby Birribiana springs.
- The bamboo is preventing the establishment of native reeds and rushes on the main upper tail of the fenced spring area.

Arguments for not acting are:

- Both species are part of the history of the area.
- The artesian water supply is demonstrably adequate to maintain a diverse native wetland flora, regardless of their presence.
- The apparent diminution of flow from the fenced spring can be ascribed to bore-sinking and the expansion of native species alone, without reference to either date palm or bamboo
- The expansion of bamboo has stopped.

6.5.2 *Management recommendations*

On balance, we recommend that:

- Young individuals of date palms be removed, but that at least some adults are kept as part of the living history of the spring.
- A trial of partial removal of bamboo, using grubbing rather than fire, be attempted.
- The trial be monitored in more detail than the current photo-monitoring provides.
- The spring group otherwise be left alone, and monitoring continued.

6.6 Big Cadna-Owie

6.6.1 *Vegetation management on the fenced vent*

There is a strong case for manipulating the vent vegetation for purposes:

- Increasing the plant diversity of the vent
- Possibly recovering hydrobiid populations, assuming individuals are still present at low density
- Potentially increasing flows and permitting enlargement of the wetland.

All entail reduction of *Phragmites* biomass and at least partial break-up of any *Phragmites* rhizome caps. Neither re-introduction of stock nor fire is considered viable at Big Cadna-owie, because of the possibility of there surviving a remnant hydrobiid population.

Mechanical disturbance can be applied without the risks inherent in either intermittent stocking or burning, provided simple appliances such as brushcutters and mattocks are used, and heavy earthmoving machinery avoided.

6.6.2 *Vegetation management on the tail*

Extending the fencing does not appear to be a viable option, as it is clear that only the current grazing is holding expansion of *Phragmites* from the upper tail, and that this too would develop to a monoculture if released from grazing.

6.6.3 *Management recommendations*

On balance, we recommend that:

- A trial be undertaken of reduction of *Phragmites* within the fenced areas by manual cutting and grubbing, for purposes of testing
    - whether the spring flow can be increased with partial removal of *Phragmites*
    - whether a local hydrobiid population remains and is capable of recovery given the habitat manipulation.
- Prior to the trial, necessary baselines be established, including
    - Documentation of the present extent of the tail wetland
    - Establishment of current flow rates from the spring
    - A further targeted search for survivors of the hydrobiid population.
- The trial itself be subject to care in design and implementation, and subsequent monitoring in detail.

6.7 Big Perry

6.7.1 Vegetation management

The most important aspect of vegetation expansion relates to hydrobiid habitat. Depending on where the hydrobiid populations are, there is a case for manipulation of dense *Typha* and *Phragmites* cover.

The concern is that there are only two functioning vents, each with a differing dominant plant. Big Perry does not therefore offer a safe environment for testing possible manipulations of the wetland vegetation. Some reduction of reedbeds may be needed to maintain even the present wetlands, but the trials to test methods should be applied elsewhere, not in this group.

As for Old Nilpinna, the presence of date palms is part of European history of the area. The palm clump is unlikely to interfere with flows from vents given its location near the end of a tail.

6.7.2 Management recommendations

We recommend that:

- Monitoring of Big Perry should be specifically targeted at establishing whether the expansion of reedbeds has in fact halted, and whether the wetland areas have stabilised or are reducing.
- Manipulation of the vegetation should be considered for the near future (2-4 years) if monitoring indicates a continued increase in reedbeds or a drying of current tails.
- Manipulation of vegetation at Big Perry should only be undertaken once trials *elsewhere* have demonstrated the validity and limitations of the manipulation options
- More information should be sought on the present distributions of hydrobiids within the spring, before deciding on what form manipulation of the vegetation might take.
- Any young individuals of date palms be removed, but that the adult tree be kept as part of the living history of the spring.

6.8 Tarlton

6.8.1 Management recommendations

There are no pressing reasons for management actions at Tarlton other than manipulations to re-start surface flows. These should be undertaken as a designed, fully documented and monitored trial. In particular, we recommend that:

- The use of fire as a management tool in *Typha* be tested in the northern spring "wetland" at Tarlton, using the other springs as controls.
- The trial be appropriately designed, with pre-burning measurement, direct recording of the burning operation, and rigorous monitoring of the outcome.

6.9 The Fountain

6.9.1 Vegetation management and fauna habitat

The Fountain is largely dominated by *Phragmites,* but still retains a small open-water tail within the fenced area. Future manipulation of *Phragmites* may be needed if the tail is further invaded.

The Fountain is an isolated spring, with no nearby sources for re-colonisation by aquatic invertebrates. Errors of both commission and omission in vegetation management may have unrecoverable impacts on invertebrate populations. Trials for the sake of trials should therefore be performed elsewhere.

6.9.2 *Management recommendations*

We recommend that:

- Monitoring of the spring be expanded to include a targeted tracking of the extent of the tail.
- Future manipulation of the *Phragmites* growth be considered, depending on results of trials elsewhere.
- Hydrobiid distributions within and outside the fenced area be monitored.

6.10 Outside

6.10.1 *Vegetation management*

Maintenance of flow from the fenced vent would normally be of some concern, given the presence in the group of two hydrobiids of very restricted distribution. Normally, manipulation of vegetation would seem appropriate both to ensure flows are maintained and to keep some relatively open water areas for hydrobiid habitat. However, given the close proximity of the unfenced vent and extensive tails, there is no pressing reason for doing so simply to maintain those habitats, given the intermittent nature of controls imposed by stocking.

The fenced vent does allow the possibility of a major trial of the effects of burning as a manipulation measure specifically aimed at *Phragmites.* Possibilities of impacts on local hydrobiid populations are mitigated by the presence of the immediately adjoining unfenced spring, from which natural colonisation or intentional assisted invasion could proceed. The unfenced spring is under no threat of accidental burning because of low vegetation cover levels.

6.10.2 *Other issues*

The alien Mosquito Fish is present in the spring.

6.10.3 *Management recommendations*

We recommend that:

- A controlled burning experiment be run on the *Phragmites* within the fenced area at Outside Spring, using the unfenced spring as a control
    - A check be made of any hydrobiids in the area to be burnt, and downstream, to ensure that the species are also present in the control area.
    - The trial to be appropriately designed, with pre-burning measurement including water flow and downstream chemistry, direct recording of the burning operation, and rigorous monitoring of the outcome.
- The possibilities of eradicating Mosquito Fish from the group be examined, with particular emphasis on possible side-effects of eradication methods on the aquatic invertebrates.

6.11 Twelve Mile

6.11.1 Vegetation management

Twelve Mile provides replicate areas on the fenced mound for experimentation. In particular, one of the older *Phragmites* dominated vents and tails could be manipulated, using the other *Phragmites* vents and tails as controls, without risk to the aquatic invertebrates on the mound as a whole. Such a trial could be undertaken in conjunction with the recommended trial of burning *Phragmites* at Outside, thus providing both grazed and ungrazed controls.

The isolated top vent allows a trial of burning *Typha* as a means for increasing surface water flow. The vent is isolated and there is no free water now present, hence no risk is posed to aquatic invertebrates. The trial could be undertaken as an adjunct to the recommended trials at Tarlton, or as a replication of them.

6.11.2 Management recommendations

We recommend that:

- The use of fire as a management tool in *Phragmites* be tested in one of the *Phragmites*-dominated springs and tails at Twelve Mile, with other *Phragmites* vents and tails used as local controls.
- The *Phragmites* trial be designed and undertaken in conjunction with the proposed trial at The Fountain.
- The use of fire as a management tool in *Typha* be tested in the isolated and now dry "top vent".
- The *Typha* trial be run as an adjunct to the trials proposed for Tarlton.
- Both trials be appropriately designed, with pre-burning measurement, direct recording of the burning operation, and rigorous monitoring of the outcome.

6.12 Coward

6.12.1 Vegetation management

At present, Coward is an example of a spring at its maximum diversity, during the changeover from a stock-induced balance to a vegetation-induced balance. This is a state which we consider it desirable to reproduce in other springs.

Accordingly, there is no immediate need to manipulate the vegetation now. However, there is likely to be such a need in the near future, given the relatively few years required for *Phragmites* dominance to reach a steady-state. Decisions whether or not to manipulate the vegetation will be required within the next three years.

Coward is an isolated spring. Given the (relative) richness of its endemic invertebrate populations, close monitoring of available fauna habitat should be undertaken in conjunction with the watch on vegetation.

6.12.2 Other issues

The top vent is already dominated by *Phragmites* and already lacks free water. It thus provides an opportunity for a trial of burning *Phragmites* with no risk to aquatic fauna (already lost, if originally present) and with ease of access for operation and monitoring.

6.12.3 Management recommendations

We recommend that:

- The level of vegetation monitoring on Coward Spring be increased, in particular to include estimates of individual species' abundance above that provided by the photopoints.
- The extent of free water be closely monitored, with regard to aquatic invertebrate habitat.
- An immediate trial of burning *Phragmites* in the top vent be undertaken, with pre- and post-burning monitoring of vegetation, wetness, and any re-invasion by aquatic fauna.
- In the longer term, and depending on the outcome of the previous three recommendations, the spring vegetation be manipulated to maintain at least a diverse set of habitats and vegetation in the tail.

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APPENDICES

SITUATION, ISSUES AND MANAGEMENT RECOMMENDATIONS FOR INDIVIDUAL FENCED AREAS

APPENDICES

J. OUTSIDE

K. TWELVE MILE

L. COWARD

M. EXAMPLES OF ENDEMIC INVERTEBRATE DISTRIBUTIONS IN SPRING GROUPS

APPENDIX A

FENCED SPRINGS GENERAL INFORMATION

A. FENCED SPRINGS

A.1 Fencing history

Springs fenced to exclude stock in the period 1986-88 were based on the priority list established by the SEA survey, with amendment to fencing proposals following consultation with the pastoral lessees involved (Harris 1992). Dimensions are given in Table A.1. Locations are given in Figure A.1.

Table A.1 Springs fenced by SA Government 1986-1988

Spring or spring group	*On landholding*	*Area fenced*	*Comment*
Blanche Cup	Wabma Kadarbu CP	1.0*	Single spring and small tail
The Bubbler	Wabma Kadarbu CP	6.3*	Single spring and large tail
Strangways	Anna Creek	0.1*	Single spring and small tail
Old Nilpinna	Nilpinna	4.0	Half of spring group
Big Cadna-owie	Allandale	0.2	Single vent, closely fenced
Big Perry	The Peake	2.7	All vents and most tails on single mound
Tarlton	The Peake	9.2	Entire group
The Fountain	The Peake	0.7	Single vent and part of tail
Outside	The Peake	0.4	One of two vents on a single mound
Twelve Mile	The Peake	2.6	All vents on single mound

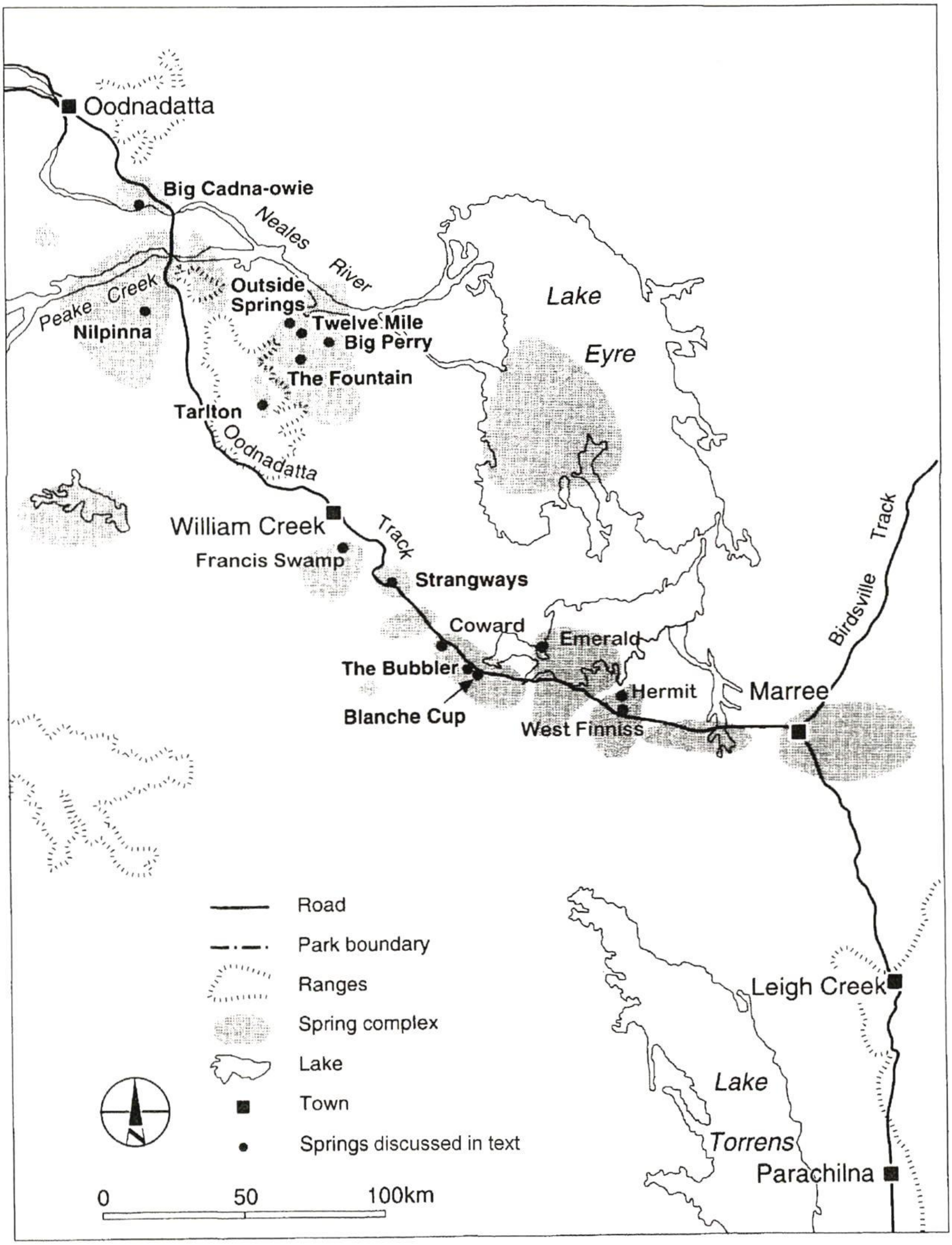
*Larger surrounding or adjoining areas now have stock excluded. Source: Harris (1992).

Subsequently, part of Old Nilpinna was fenced in 1992 and Coward Springs was fenced in 1996. In both cases, a major vent and its tail were fenced, without the fence confining the vent.

Extensions to the fenced areas at Blanche Cup and The Bubbler, and the effective fencing of the Little Bubbler, was achieved with the reservation and fencing of the Wabma Kadarbu Mound Springs Conservation Park in 1995.

The major portion of the terraces at Strangways Springs (Strangways Repeater Station) was fenced by S Kidman and Co. in 1996. Freeling Springs, at the Peake Telegraph Repeater Station ruins, was largely removed from domestic stocking about the same period. It is not a group monitored as part of the fencing program.

Figure A.1: Springs examined or referred to in this study



Source: modified from Harris (1992)

A.2 Field inspection

The fenced springs were visited in August 1998, in company with DEHAA staff on their annual inspection. Rapid vegetation records were also undertaken over this period, using the methods applied in monitoring of springs by WMC Resources for the Olympic Dam operations (Fatchen & Fatchen 1992). Sampling and analysis was not a significant part of the current brief, and hence was not undertaken as extensively or systematically as would be the case for a full monitoring survey. Nevertheless the data provide at least a touchstone for comparison with the intensively monitored springs elsewhere. Additional to fenced springs, some other groups were also visited and partially sampled, with vegetation data recorded. Sampling is summarised in Table A.2

Table A.2: Sampling in spring groups, August 1998

Spring group (Fencing program springs in CAPITALS)	*No. of springs in group**	*No. of vents and/or tails sampled Aug 1998*	*Total sampling units Aug 1998*
BIG PERRY	7	5 vents + upper tails, 1 lower tail	6
BLANCHE (includes Blanche Cup and the Bubbler)	6 (2 originally fenced)	2 vents, upper and lower tail	4
COWARD	One mound, multiple vents	3 vents, upper and lower tail	5
Elizabeth	47	2 vents	2
Francis Swamp	42	8 vents, 5 tails	13
Freeling	21	3 vent areas	3
Jersey	4 + seepages	6 vents, 4 tails	10
Kewson Hill	17	2 vents	2
Levi	6	4 vents, 1 bore	5
Milne Bore and Spring	5	2 vents, 1 tail 1 bore drain	4
Ockenden	1	1 total wetland	1
OLD NILPINNA	3	3 vents, 5 wetland areas	8
OUTSIDE	5	2 vents, 2 tails	4
Strangways (outside original fenced area)	13 +	9 vents	9
STRANGWAYS (originally fenced spring)	13	1 vent, 1 tail	2
TARLTON	7	7 vents, 1 tail	8
THE FOUNTAIN	1	1 vent, 1 tail	2
The Vaughan	1	1 vent, 1 tail	2
TWELVE MILE	8	8 vents, 4 tails	12
Walkarina	4	1 vent	1
Welcome Spring (Beresford spring complex)	1	1 vent, 1 tail, 1 bore drain	3

*Number of springs in groups from Darren Niejalke (pers comm), modified by field observation.

A.3 Use of repeated photographs

Spring monitoring has been limited by lack of funds (Harris 1992). Monitoring procedures were proposed and demonstrated (Fatchen & Associates 1986) but only the photographic components could be maintained. The photographs themselves have limitations.

- Growth in many of the fenced springs has forced the relocation of photopoints. Viewpoints change as a result.
- The points themselves have not been strictly controlled. For the Olympic Dam monitoring, permanent pegs are used to ensure that the same photograph is taken each time: there are various reasons, including the important aesthetic impact, why pegs could not be used in the fenced springs. Accordingly, there is a great deal of wander in photoseries.
- Variation in camera lenses, from 50mm focal length to 35mm "compact" cameras, create further interpretation problems. Photoseries reproduced here have been manipulated to rectify, approximately, the differing outcomes of differing focal lengths. Some detail is lost in the process.
- Photographs can only deal with the obvious and major species. Cryptic plant species are either not visible or not identifiable.

Nevertheless, despite these difficulties in comparison and interpretation, photographs represent the one source of firm data as regards the fenced spring dynamics. As well as general comment on the photos, biomass trends in major plant species have been plotted, using the method of Noble (1977). Conventions used in following sections are:

- Plots of biomass traces are unscaled, except where cover-abundance data are available and can be matched to the particular photograph. Biomass traces show relative changes but give no indication of absolute values.
- On most plots, individual species' biomass traces are ranked, with the most abundant as the uppermost plot.

A.4 Comparative plant data for springs visited in August 1998

From the sampling indicated in Table A.2, it is possible to construct some generalised comparative plots using the vegetation data, to highlight obvious variation through the sample. Plots presented here all have been generated using data for non-alien, semi-aquatic plants only. The following are provided:

- Median cover for the sample set from each group
- Total species richness within each group, for non-alien semi-aquatic plants
- Median plant cover diversity for the sample set from each group
- Where feasible, outside/inside comparisons for fenced groups.

All relate directly to the dynamics and the biodiversity of spring wetlands. The cover is of particular importance given the stimulus for this study, of spring vegetation expanding after fencing. Species richness and cover diversity allow different aspects of plant diversity to be examined. The direct outside-inside fence comparisons are possible for some springs where fencing has only partially included a group.

Reference is made to these comparative plots in subsequent sections dealing with individual springs.

A.4.1 Plant cover

The projective cover of plants was scored, using the Domin cover-abundance scale, for each sampling unit in field visits. It allows both between-species comparisons and at least a scaled indication of the denseness of the cover on a wetland. It is not however an equivalent to biomass: the total cover that can be estimated for any one species is 100%, regardless of whether the cover is a low sward or a tall reedland. The median cover on fenced and unfenced springs is ranked in Figure A.2

A.4.2 Plant species richness

Species richness, the number of species present, is a rather rough index of local diversity. It allows differentiation between species-poor and species-rich groups, but does not quantify differences in the abundance of individual species. Excluding aliens, and dealing only with semi-aquatic plants, the species richness is ranked for each group in Figure A.3. The *de facto* fenced very large Hermit and West Finniss groups are provided for comparison.

A.4.3 Plant species cover-diversity

Cover-diversity in this report is calculated from the cover data using the Shannon-Wiener information function (H) as a diversity index. This measures the *equitability* of species, via their relative abundance. A spring with equivalent cover of each of several species will generate a high diversity index: a spring largely dominated by one species will generate a lower index, and a spring containing only one species will generate a *zero* diversity index. The median diversity within each group is ranked in Figure A.4. Hermit and West Finniss groups are shown (1998 data) for comparison.

A.4.4 Inside/outside comparisons

Fencing at Outside Springs, Big Cadna-owie, Strangways (Repeater Station) and Old Nilpinna, by accident or design, allows some direct comparison between fenced and unfenced areas in close proximity. In the first three cases, the fenced sample is a single spring. Comparisons are indicative only, but support the photographic information. Cover differences are shown in Figure A.5, species richness differences in Figure A.6 and plant cover-diversity in Figure A.7

FIGURE A.2 Median cover, semi-aquatic plants, August 1998

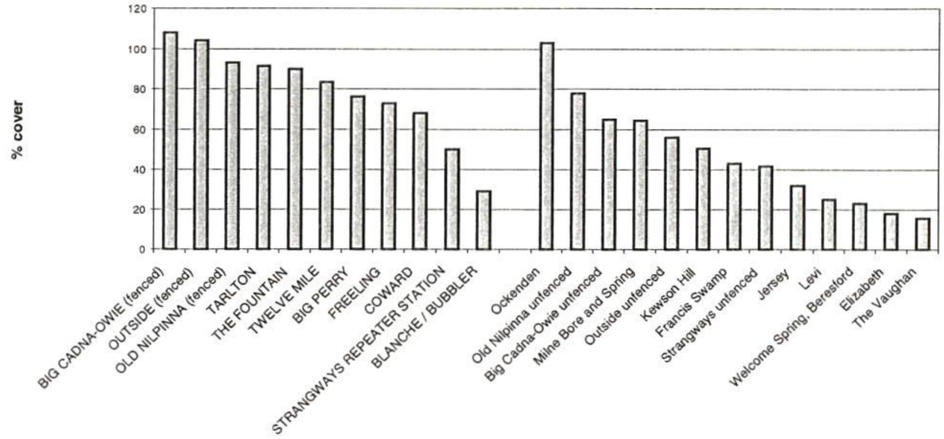


FIGURE A.3: Semi-aquatic plant species richness, 1998
(Aliens excluded)

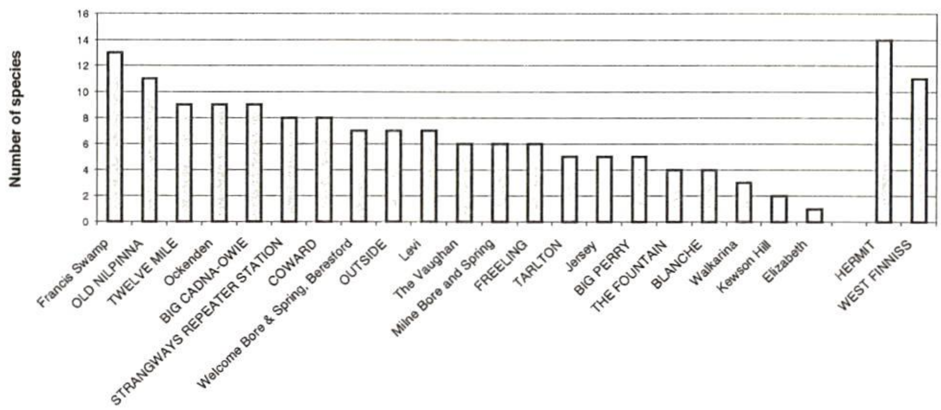


FIGURE A.4: Median cover diversity (H) of non-alien semi-aquatic plants by sampled spring group, August 1998

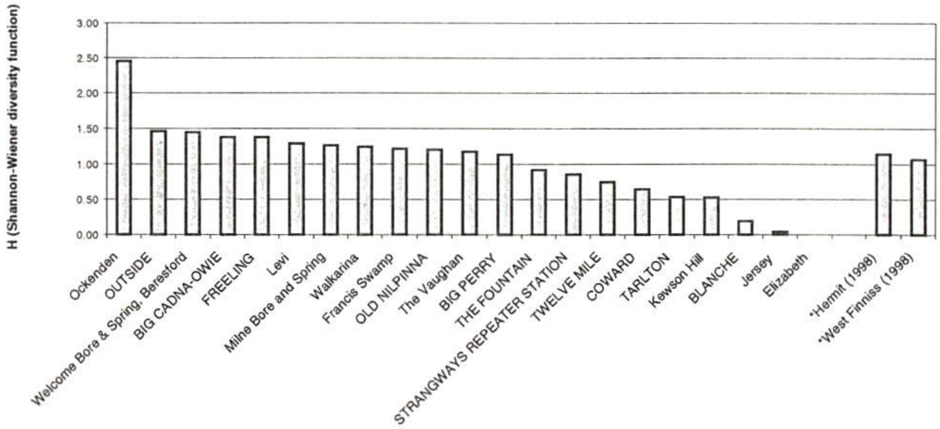


FIGURE A.5: Differences in plant cover between adjoining fenced and unfenced spring areas

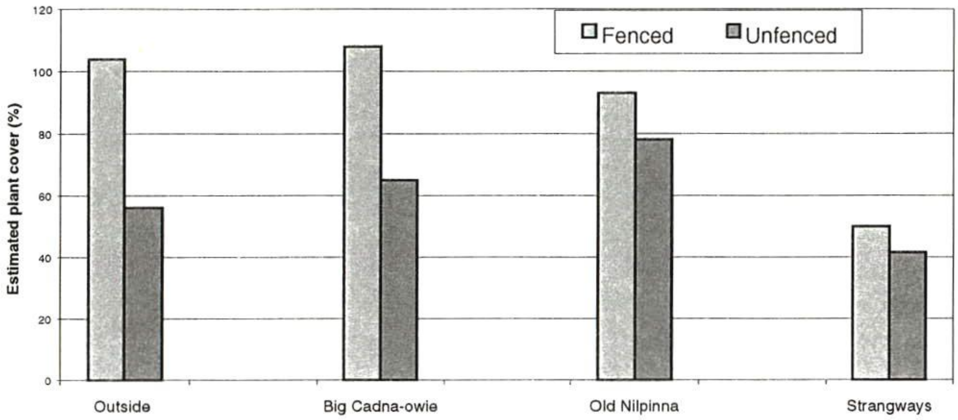


FIGURE A.6: Differences in plant species richness between adjoining fenced and unfenced spring areas

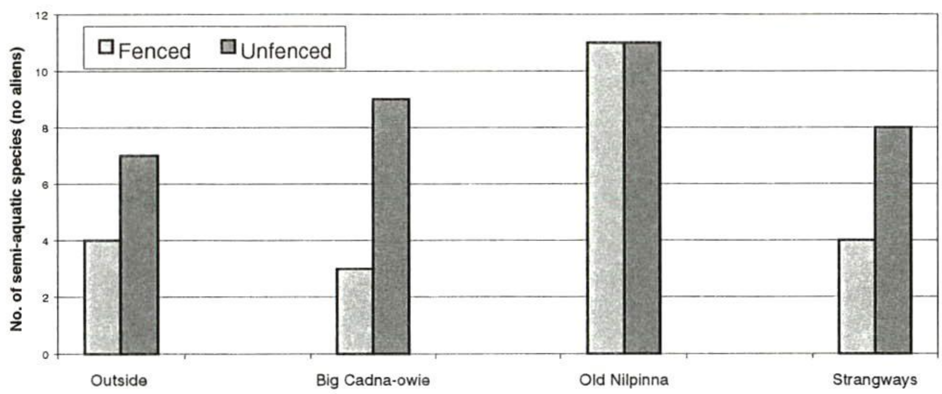
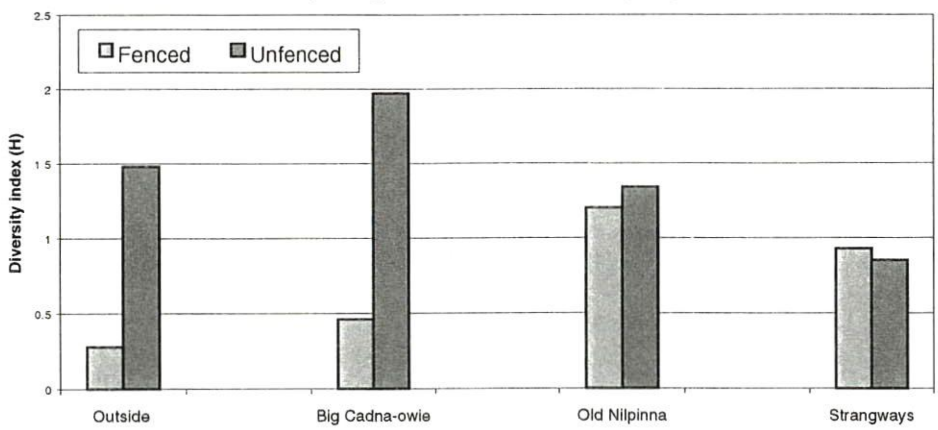


FIGURE A.7: Differences in plant cover-diversity between adjoining fenced and unfenced spring areas



APPENDIX B

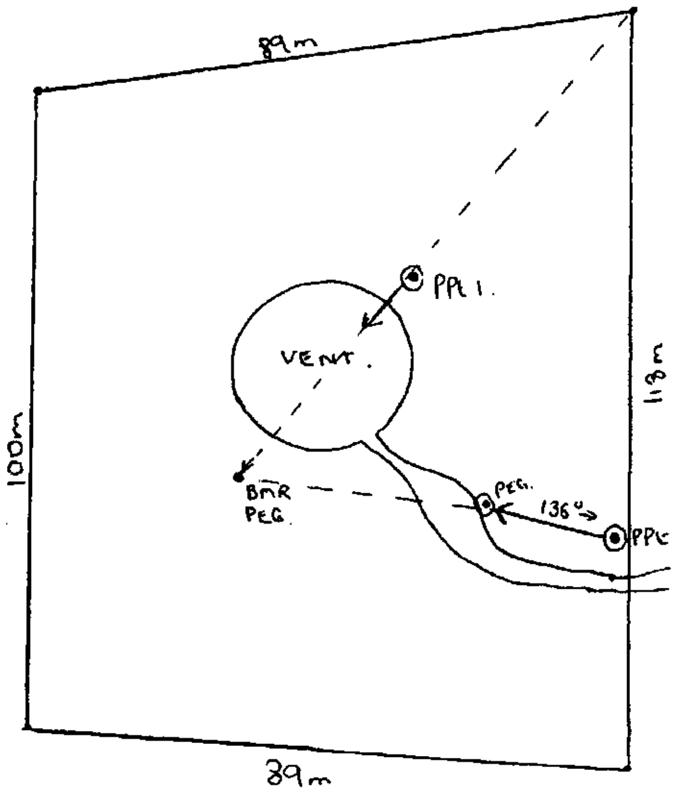
BLANCHE CUP

B. BLANCHE CUP

B.1 General

The Blanche Cup mound and spring within the Blanche spring group was fenced in the first round of conservation fencing, in 1985. The fence was placed close around the perimeter of the mound (Figure B.1).

Figure B.1: Fencing on Blanche Cup



Misleadingly, Blanche Cup is often cited (eg in Greenslade et al 1985, in general tourist literature, in Boyd 1990) as an excellent example of mound spring development. It is a good example of conical limestone mounds built by a long term spring; a series of similar examples are present at Horse East springs, currently proposed for addition to the Wabma Kadarbu CP. The large conical form, rather than providing a mound spring archetype, is in fact unusual when considered against the full spectrum of springs west of Marree. The Blanche spring group generally contains a mixture of springs on limestone mounds, mostly extinct or with very little water present, and springs on low silty gypseous mounds, such as the Bubbler (Appendix C) and the Little Bubbler.

The Blanche Cup spring group, in common with other spring groups in the Coward Spring Complex, has the endemic hydrobiid snails *Fonscochlea zeidleri, F. aquatica, F. variabilis* and *Trochidrobia punicea*. Blanche Cup itself is the type locality for the ostracod *Nagawara dirga* (De Dekker 1979), which has subsequently been found common and widespread through the mound springs generally.

The semi-aquatic flora associated with Blanche Cup itself is depauperate, limited to the bore drain sedge *Cyperus laevigatus*, pondweed *Potamogeton pectinatus*, but with an identification of *Ruppia sp.* from the Blanche Cup pool (F Badman pers comm).

B.2 Condition

SEA (1984) commented on tourist and stock damage of the mound sides and partial trampling and infilling of the pool edges. Blanche Cup and The Bubbler together have been a long-term focus for tourism in the region. Recognising the potential for damage to spring limestone at Blanche Cup and to the silty mound at The Bubbler, SA Government conservation initiatives have included the construction of boardwalks to allow use with damage minimised.

The main concern for changes in condition at Blanche Cup mainly relate to visitor damage, as evident in the photo series (below).

B.3 Changes in incidence of plant species since fencing

The pool (vent) at Blanche cup shows no change in species composition since prior to fencing: species present since 1983 (WMC data) are *Cyperus laevigatus* and *Potamogeton pectinatus* (and, probably, *Ruppia* sp, confused with *Potamogeton* in field scoring). In particular, unlike other, smaller vents in the whole group, there has been *no* invasion of *Phragmites* since fencing. The tail, on the mound side, has only had one invasion, of a single individual of coolabah *Eucalyptus coolabah*, which appeared in 1996/97.

B.4 Expansion of wetland vegetation in fenced areas

B.4.1 Dominance and wetness changes

There has been no dominance shift in vegetation and the pool has remained present. However, both photographic evidence and measurement as part of the WMC monitoring both indicate a shrinking of the pool (Figure B.4). The tail on the mound slope has oscillated in size. *Cyperus laevigatus* had begun to establish on the formerly bare tail outside the fenced area in 1997, a consequence of exclosure from stock over the whole Wabma Kadarbu CP.

B.4.2 DEHAA photoseries

Figure B.2 shows the following changes in wetland vegetation of the pool. All photos post-date fencing.

- Between 1986 and 1994, an increase in height and cover of the monoculture *Cyperus laevigatus.*
- From 1995 to 1997, a trampling/compaction of pool edges with some loss of *Cyperus laevigatus.*
- Also from 1995 to 1997, what appears to be a shrinkage of the pool and wetland
- Between 1997 and 1998, some recovery of pool area and of *Cyperus laevigatus.*

Biomass trend (*Cyperus laevigatus* only) for the photoseries shows similar variation (Figure B.3): the biomass in 1998 is still somewhat higher than that in 1986.

FIGURE B2
BLANCHE CUP VENT
DEHAA PP1

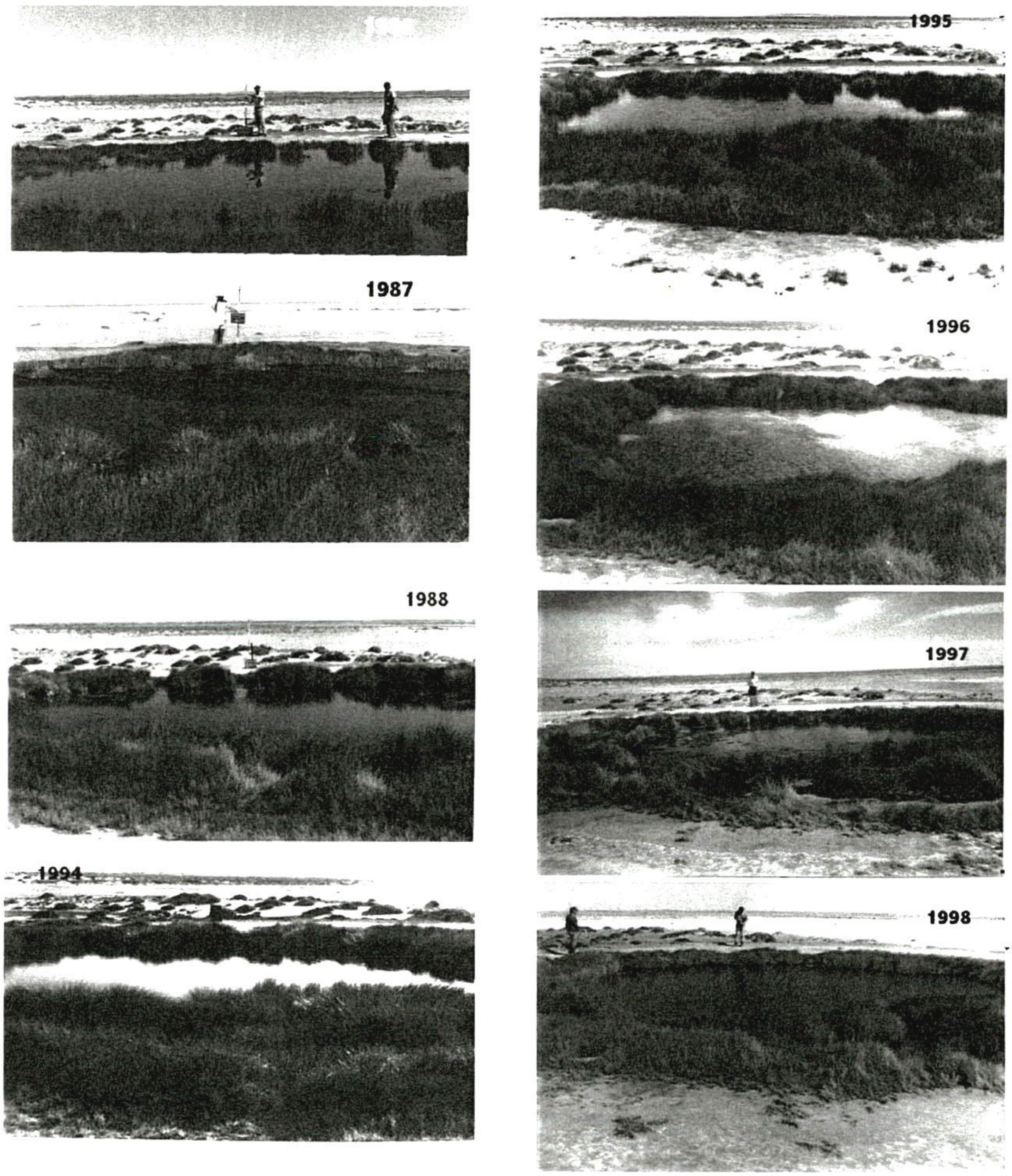


FIGURE B3 Blanche Cup (PP1) Biomass trend

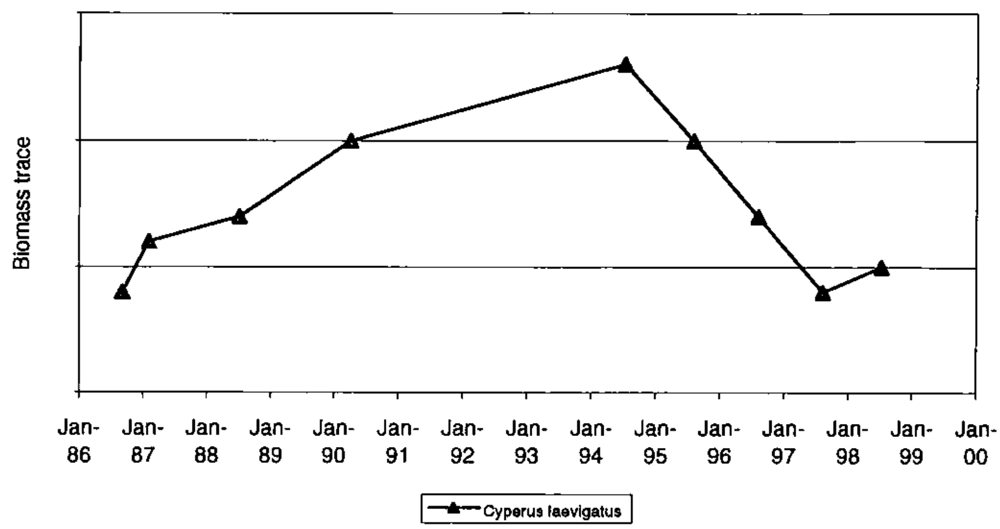
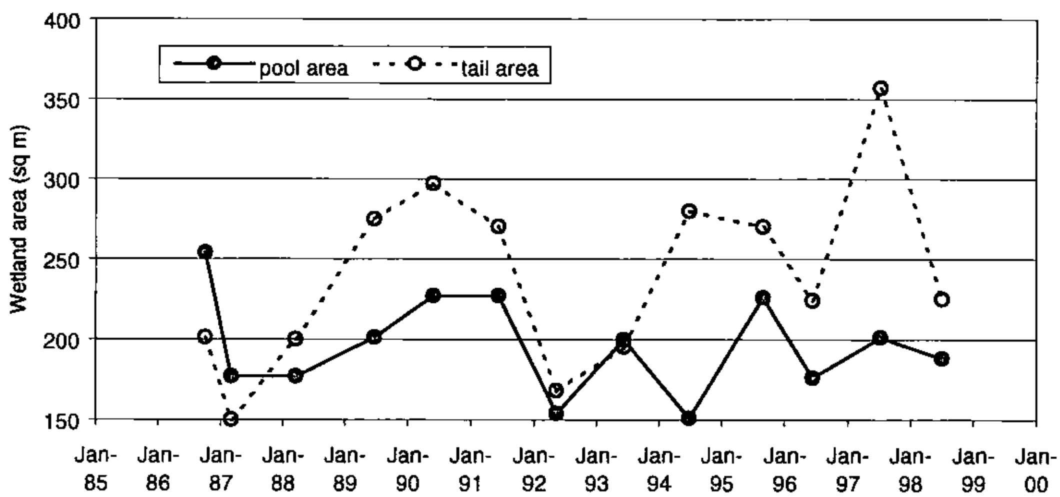


FIGURE B.4 Blanche Cup pool and tail wetland areas 1986-1998



B.5 Cover and plant diversity in context

The wetland vegetation on Blanche Cup is depauperate, with diversity approaching zero, and a relatively low cover, in contrast to most of the fenced springs (Figures A.2, A.3, A.4). There is no indication of invasions and no indication of vent plugging.

B.6 Interpretation

The absence of expansion in vegetation following fencing may be a consequence of particular water chemistry; a similar effect has been noted at The Bubbler.

The values which may be associated with Blanche Cup are therefore primarily to do with its geomorphology, particularly its formation, and in its use as a tourism focus and the education/interpretation opportunities this provides.

Damage to the more friable parts of the mound seems to have been reduced by the installation of a boardwalk, and the remaining source of damage appears to be the compaction and partial infilling around the pool.

B.7 Management issues and necessary actions

B.7.1 Vegetation management

There is no reason evident for considering active vegetation management.

B.7.2 Other issues

The impact around the Blanche Cup pool could only be reduced by installing some form of boardwalk. While this might stop the infill of the pool, it would certainly detract from the visitor experience and potentially cause major problems for the spring itself. In particular, any fracture of the spring limestone could well result in development of a new tail and the lowering of the pool. Compaction and infill appeared to have halted in 1998.

B.7.3 Management recommendations

We recommend that:

- No vegetation management be undertaken
- No action be taken to extend the existing boardwalk or to cover the rim of the pool, given the possible consequences of the necessary engineering to anchor structures
- Impacts of tourist use continue to be monitored.

APPENDIX C

THE BUBBLER

C. THE BUBBLER

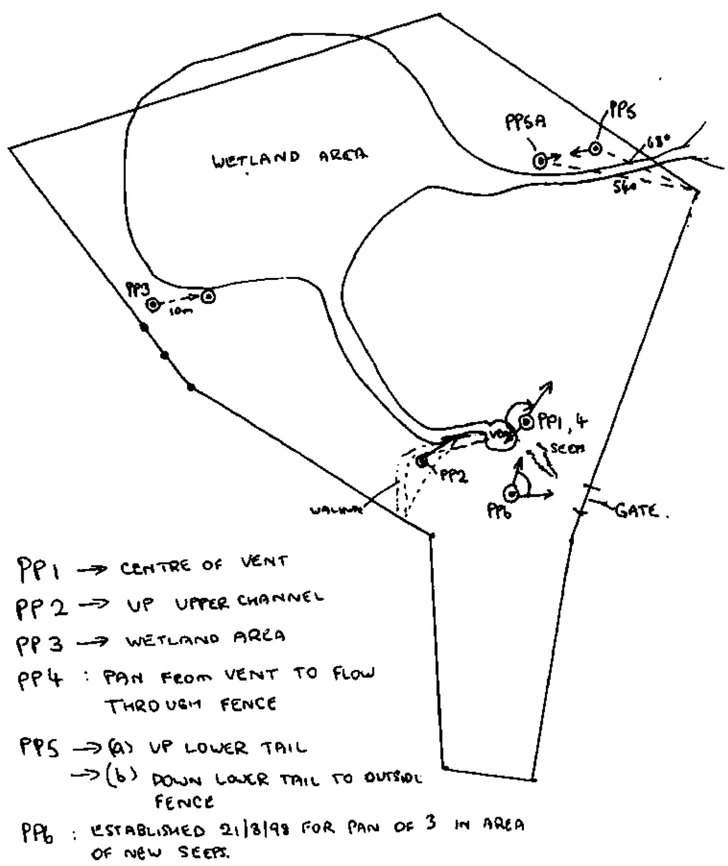
C.1 General

The Bubbler is a very fast-flowing vent set in a low silty mound, debouching through a narrow gutter onto a level floodplain, allowing the development of an extensive tail. Comments in Appendix B relating to the fauna in the Blanche Cup spring group as a whole also apply here. Its flora is slightly less depauperate than Blanche Cup, with *Schoenoplectus litoralis* present.

The spreading of a large tail on a flat floodplain is likely to mean that seasonal conditions will affect the extent of the vegetated wetland, with areas expanding when surface water subsidies are available (rain, floods) and contracting in drought.

The Bubbler and part of its tail was fenced in 1985 (Figure C.1). Fencing of the Wabma Kadarbu CP effectively protected the rest of the tail from domestic grazing.

Figure C.1 Original fencing of The Bubbler



C.2 Condition

Together with Blanche Cup, The Bubbler provides the primary tourism focus for mound springs in the region. Unlike Blanche Cup, The Bubbler was very heavily impacted by cattle, as was the similar Little Bubbler, at times almost totally devoid of vegetation. Following exclosure, impacts primarily came from tourism visitation.

The establishment of a boardwalk has reduced the degree of visitor impact around the main vent.

Additional minor seeps and vents were noted in August 1998. These are unlikely to have arisen from the "plugging" effects of the limited amount of vegetation in the strongly flowing main vent, but may indicate aquifer recovery following reduction of water use in the region.

There are no figures available on tourism use. From direct observation, visit duration tends to be short, but with frequent arrivals and departures at least during winter months.

C.3 Changes in incidence of plant species since fencing

There have been no overt changes in the plant species present as a consequence of either the initial fencing or later fencing. The semi-aquatics present are *Schoenoplectus litoralis* and *Cyperus laevigatus,* with floodplain species *Halosarcia indica, H. halocnemoides* and *Nitraria billardieri* in the tail. Despite extensive invasions and expansions of *Phragmites* elsewhere within the Conservation Park, there has been *no* invasion into the Little Bubbler tail to 1998.

C.4 Expansion of wetland vegetation in fenced areas

C.4.1 Area and biomass changes

The area of vegetated tail has expanded greatly with the removal of stock, with two steps involved: an increase up to 1995 within the original fencing, and a subsequent increase following fencing of the Park area in 1995. There is some indication from the DEHAA photographs that the vegetated wetland area is stabilising. The relative vegetated area continues to increase (panoramic photographs, Figure C.2): however, biomass in the longest fenced part of the tail has peaked and is declining (Figure C.4).

C.4.2 Dominance changes

Accompanying the removal of stock and the increased biomass are dominance changes. In the upper part of the tail, abundance of *Schoenoplectus litoralis* has dropped relative to increasing *C. laevigatus* (Figure C.3), and in at least one area there is an increase in floodplain species, establishing on formerly permanently wet ground (Figure C.4).

C.5 Cover and plant diversity in context

As for Blanche Cup, the wetland vegetation is depauperate, with diversity approaching zero, in contrast to most of the fenced springs (Figures A.2, A.3, A.4).

C.6 Interpretation

The vegetated wetland may be expected to continue expanding. The increased biomass in the tail will eventually result in apparently drier conditions. Especially, the extreme ends of the vegetated tail may fluctuate, depending on seasonal conditions. The *C. laevigatus* cover haying-off or expanding may give the impression of flow reductions or increases, regardless of whether flows have changed.

At present, the most likely predicted result of the appearance of minor subsidiary seeps on The Bubbler mound is for the invasion of *Cyperus laevigatus.*

FIGURE C.2 Bubbler Tail Vegetated wetland
Relative area from panoramic photographs

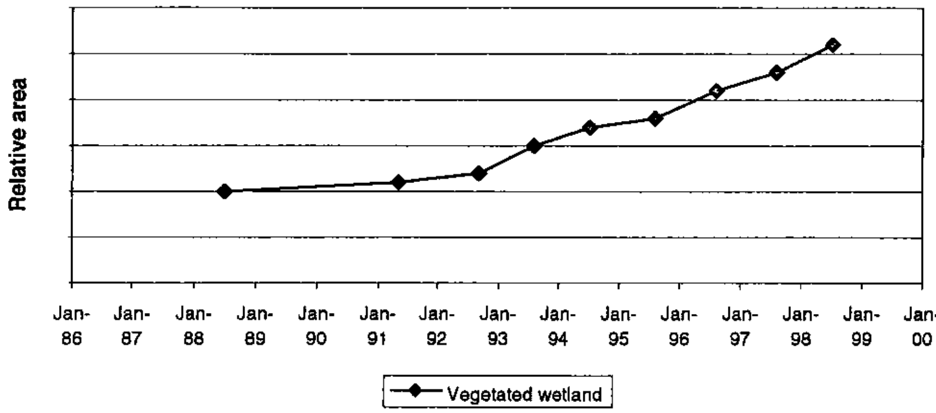


FIGURE C.3 Bubbler Lower Tail PP3 Wetland Biomass Trend

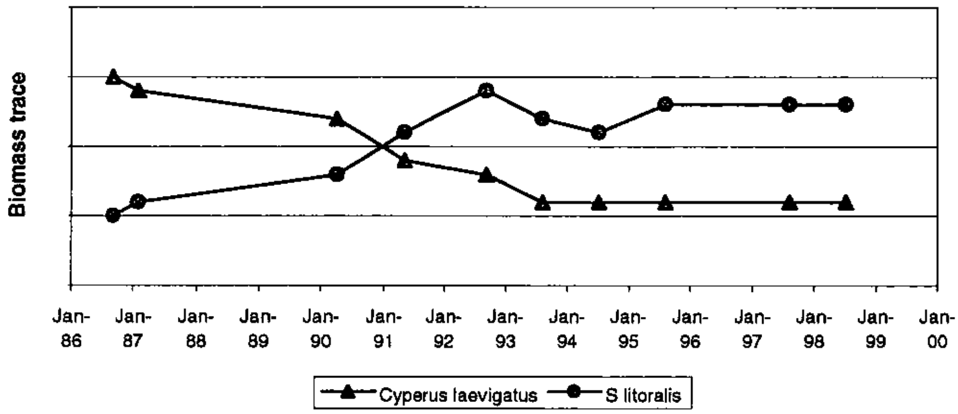
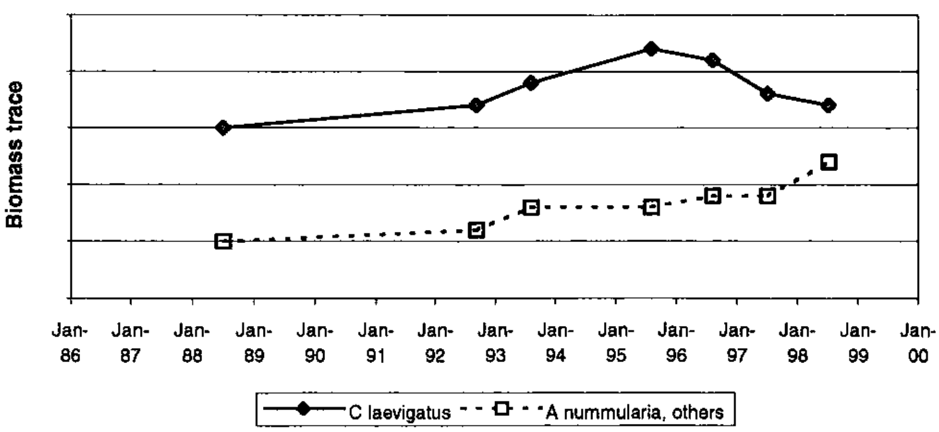


FIGURE C.4 Bubbler Lower Tail PP5 Biomass Trends
(solid lines - wetland species; dotted lines - dryland species)



C.7 Management issues and necessary actions

C.7.1 Vegetation management

There is no reason evident for considering active vegetation management.

C.7.2 Other issues

While the expansion of the vegetated wetland will result in drier conditions on the tail extremities, none of the wetland species involved are likely to block either water or light from the aquatic fauna, and none are capable of stopping strong flows entirely. This situation may alter if *Phragmites* eventually invades the tail.

C.7.3 Management recommendations

We recommend that:

- No vegetation management be undertaken
- Impacts of tourist use continue to be monitored.
- Monitoring be expanded to cover the new subsidiary vents.

APPENDIX D
STRANGWAYS

D. STRANGWAYS

D.1 General

The Strangways (Telegraph Repeater Station) group is a series of travertine terraces with numerous vents, most of which appear to be waning. Recent fencing by S Kidman and Co. has enclosed the main area of terraces, providing protection for the landform, springs, and part of a local population of the rare plant *Hemichroa mesembryanthemum.*

The spring fenced in 1986 as part of the DEHAA spring conservation program is on the edge of the now-fenced area, at a slightly lower level than most of the local vents. It was selected for fencing as the largest spring (as regards water volume) in the area, and the one for which most documentation existed.

Strangways group contains the relict plant species *Gahnia trifida,* also present in the Hermit Hill area, at Francis Swamp and at Freeling Springs. This species does not appear on springs either within the old or new fenced area.

Strangways group shares with the Billa Kalina, Emily and Francis Swamp spring groups the narrow endemic hydrobiid *Fonscochlea billakalina.* (Tapp and Niejalke 1998). Aquatic invertebrates otherwise are equivalent to those of Coward Spring and the Blanche Cup spring group (Appendix M).

Springs within the group have very low flows. It is obvious from the terraces in the group that flows were much greater in the past, and 19th Century reports indicate greater flows in the recent past (Harris 1992).

As with the Francis Swamp area, the spring vegetation and surrounds also give the impression that the group is waning, particularly in view of the extent and frequency of true halophytic plants such as *Halosarcia halocnemoides.* Strangways however is well into the area of sulphated waters. The appearance of a waning group, given by the vegetation, may be misleading. Water chemistry may also be the reason for the monitored spring in Strangways responding very differently to the release of grazing pressure to the monitored spring in Coward (Appendix L).

D.2 Changes in incidence of plant species since fencing

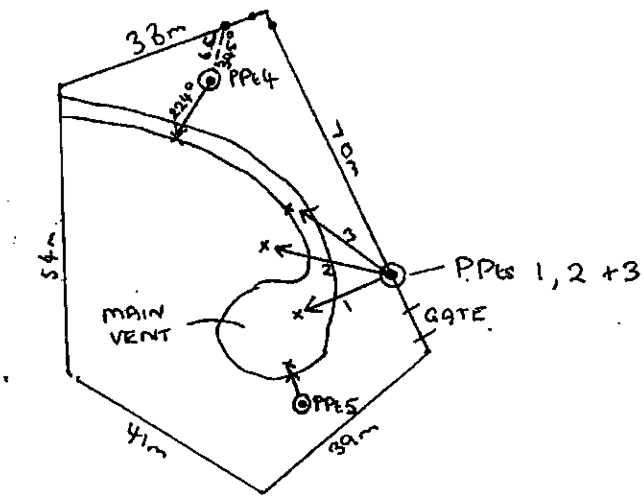
As best can be determined without a species listing for the fenced spring at the time of fencing, there appears to have been no change in the plant species present. For the whole group, the only addition to the 1978 listing of species by Symon (1985) is the rare terrestrial plant *Hemichroa mesembryanthemum*

Wetland or wetland-edge species at the 1986 fenced spring are *Cyperus laevigatus, Schoenoplectus litoralis, Halosarcia indica* and *H. halocnemoides.*

D.3 Changes in wetland vegetation in fenced areas

The 1986 fenced spring is monitored by photopoints (Figure D.1)

Figure D.1 Strangways original fenced area



Figures D.2 and D.3 provide portions of the DEHAA photoseries. The main differences between 1986 and 1998 in wetland vegetation relate to abundance of *Halosarcia* spp on vent and tail edges.

Following the release from domestic stocking, the following changes took place within the spring pool (Figure D.4):

- *Cyperus laevigatus* increased to 1991, declined almost back to its pre-fencing biomass to 1996, then increased slightly. The bulk of wetland biomass in the pool is provided by this species.
- *Halosarcia* spp established on the edge of the pool, peaking in 1995 but subsequently declining.
- *Schoenoplectus litoralis* biomass has oscillated, with the main differences being in location of clumps of the species.

Within the spring tail, almost entirely in the fenced area (Figure D.5):

- *C. laevigatus* increased to a peak in 1992, then reduced to the present, with less biomass than in 1986.
- *Halosarcia* spp on the tail edge and end increased to 1992, then declined, with many of the mature bushes now dead or almost so, and little recruitment. *H. indica* lines the upper part of the tail, with *H. halocnemoides* on the lower portion and at the tail end.

FIGURE D.2 STRANGWAYS FENCED POOL

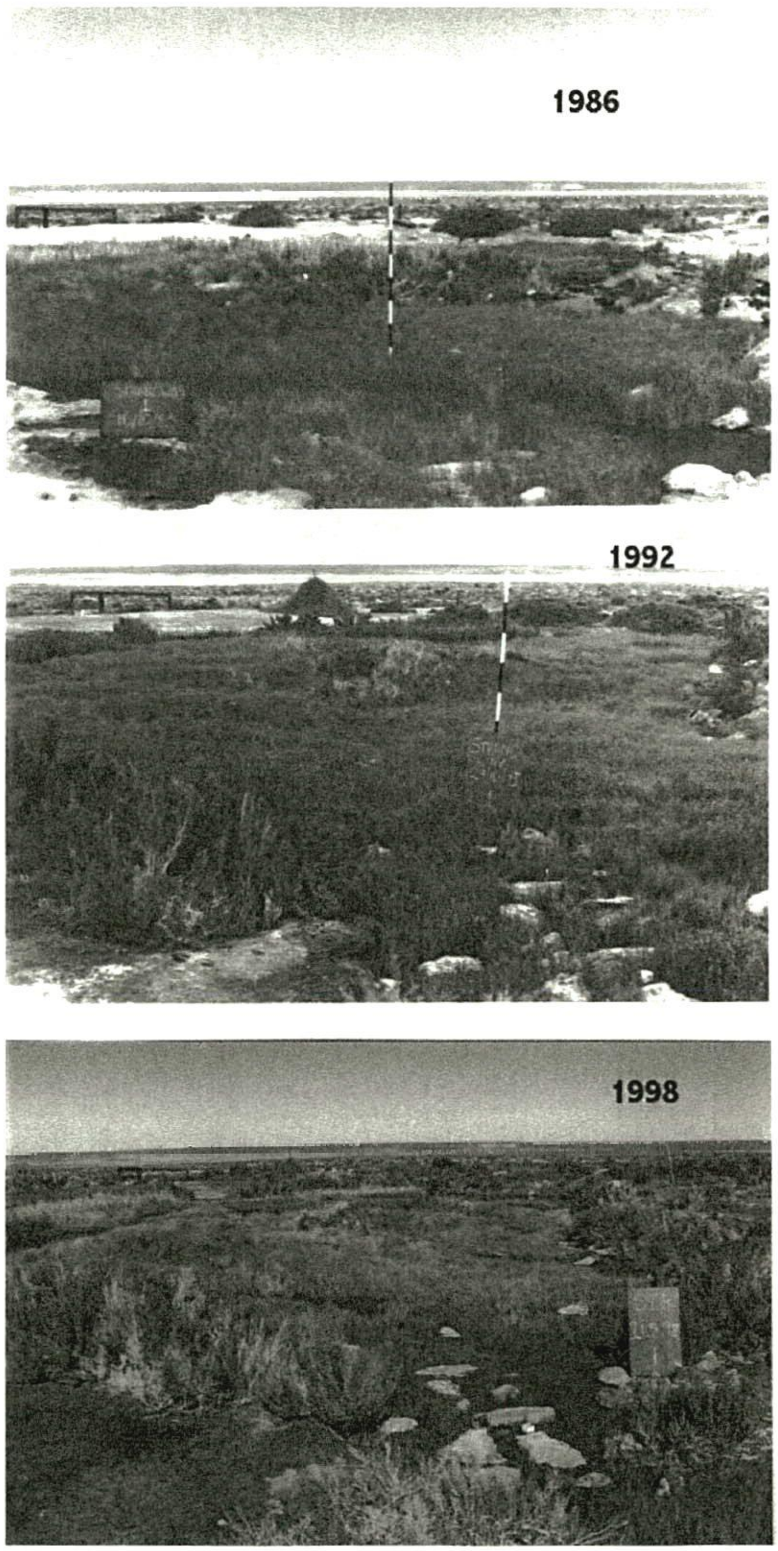


FIGURE D.3 STRANGWAYS FENCED TAIL

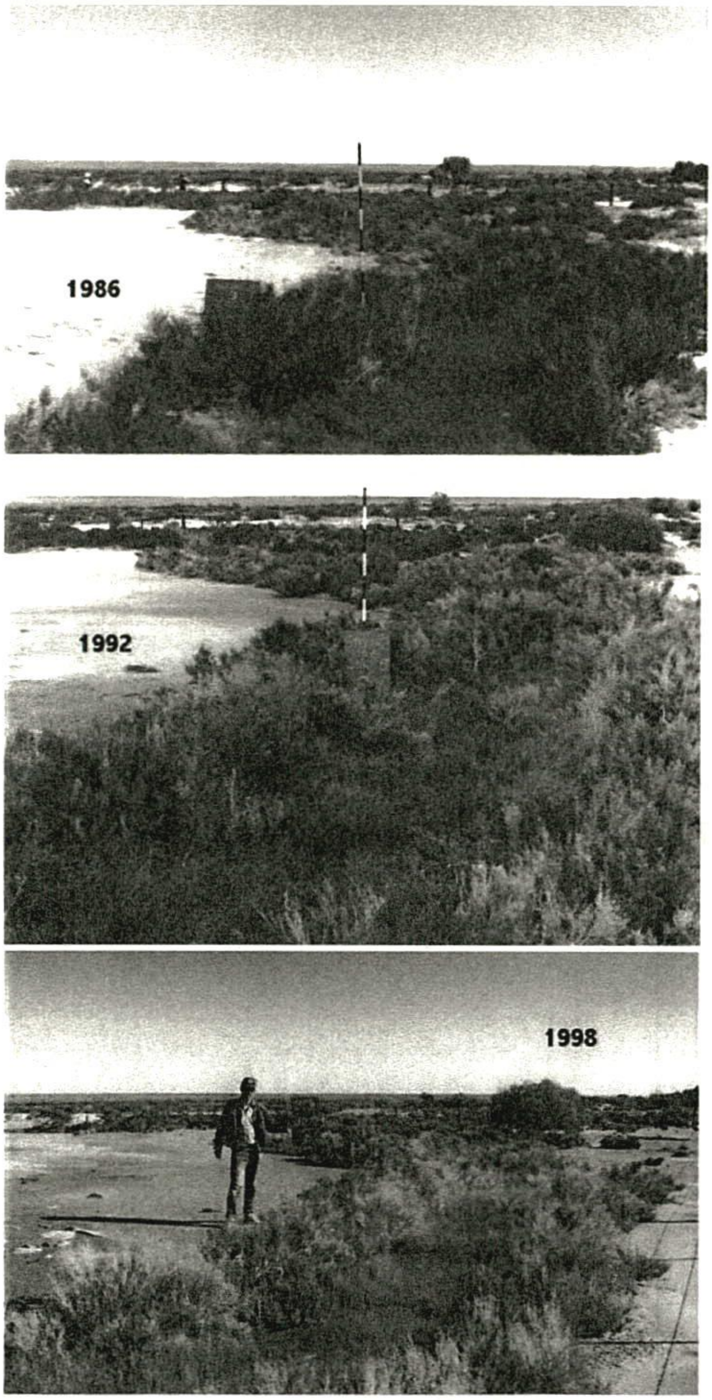


FIGURE D.4 Strangways Repeater Station PP1 (fenced pool)
Biomass Trend

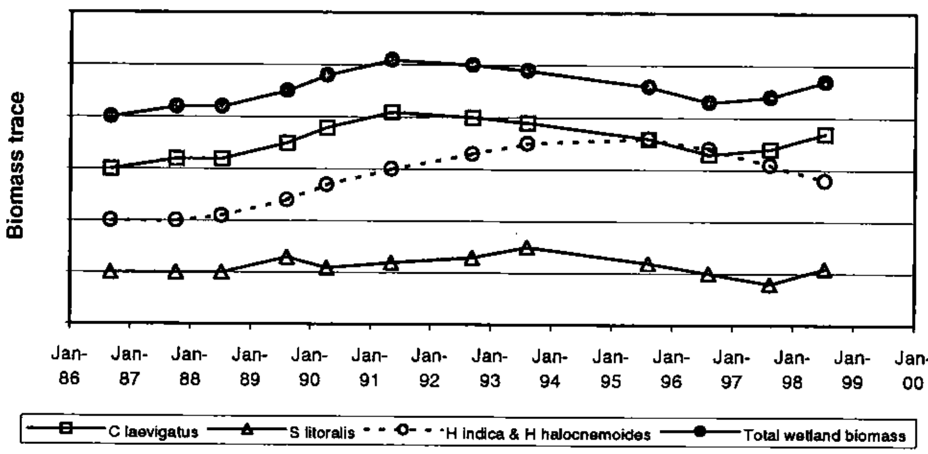
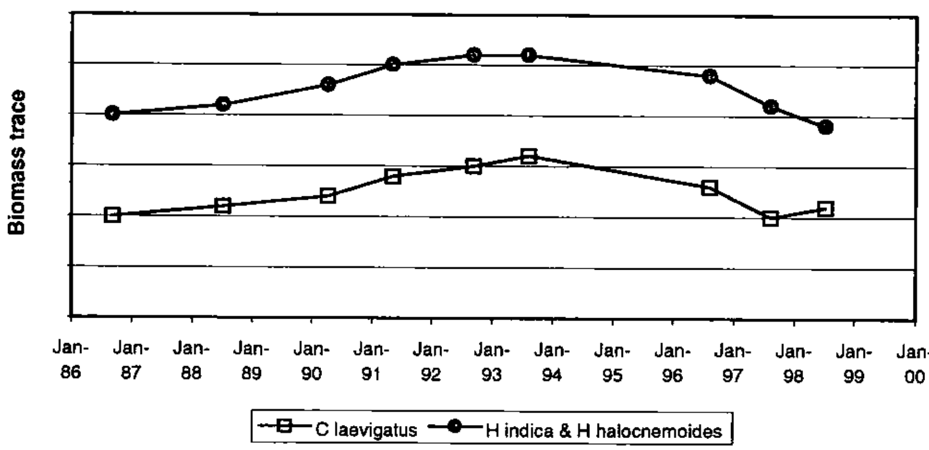


FIGURE D.5 Strangways Repeater Station PP3 (Fenced Tail)
Biomass Trend



D.4 Cover and plant diversity in context

Data from the Strangways group as a whole was used in comparisons with other fenced springs in Figures A.2 to A.7. Springs within the 1986 and recent fenced areas have lower cover than most other fenced springs (Figure A.2), have high species richness (Figure A.3) but relatively low cover-diversity.

Cover on springs inside fenced areas is marginally higher than cover outside, and there is little difference in cover-diversity. However, species richness on springs *outside* the fencing appears to be nearly double that inside. This may be a result of a limited sample, but also arises due to species such as *Gahnia trifida* not being included within the fencing.

D.5 Interpretation

The distribution of the halophyte *H. halocnemoides* in the tail of the 1986 fenced spring almost certainly indicates increasing soil salinity. The salinity may be the reason for the failure of *Phragmites* even to invade, let alone dominate the spring, despite its present nearby in the group. The relatively little change in the spring is in stark contrast to the rapid and significant changes occurring in Coward Springs, and the expansion of *Phragmites* and/or *Typha* in fenced springs further north.

The spring is a demonstration of the possible influences of both flow and water chemistry in limiting changes following release from domestic stocking. It is also possible that the spring, being one of numerous springs in the area, was not in fact heavily impacted by domestic grazing and hence was not being held in a stock-induced balance. However, Frank Badman (pers. comm.) suggests that this spring, being on the outer edge of the group, would have been one of the most heavily grazed and pugged in the group.

D.6 Management issues and necessary actions

D.6.1 Vegetation management

There is no basis for manipulative vegetation management within the group.

D.6.2 Other issues

There is a need for monitoring of springs both within and outside the larger fenced areas, particularly to establish whether the group is in fact declining. Reasons for this include both the presence of the narrow endemic hydrobiid *Fonscochlea billakalina* and the maintenance of local populations of *Gahnia trifida.*

The rare terrestrial species *Hemichroa mesembryanthemum.* Is currently being monitored by the local Soil Board. Continuation of this monitoring with the spring monitoring is suggested.

D.6.3 Management recommendations

We recommend that:

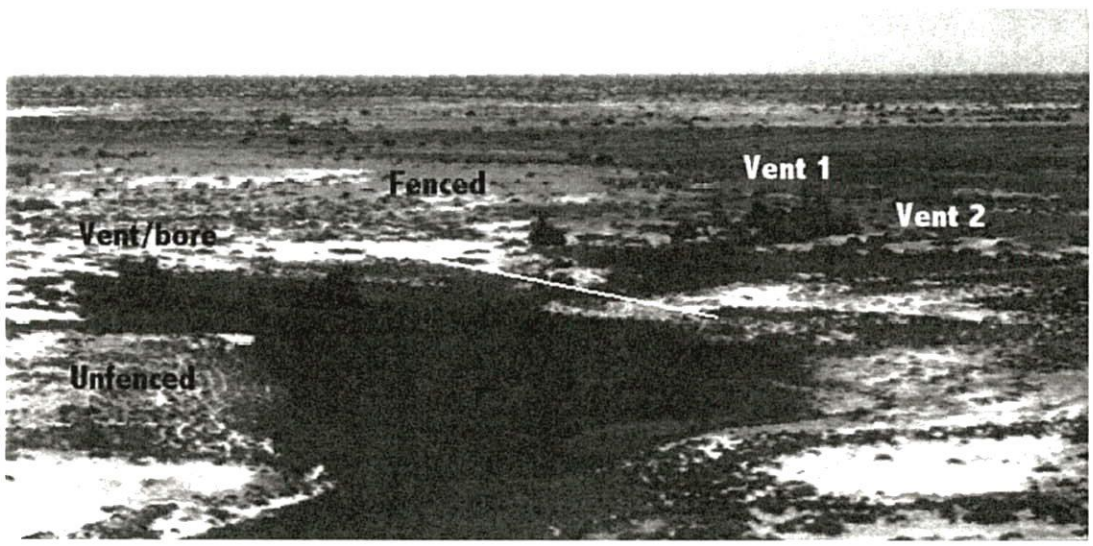
- No vegetation management be undertaken
- The current monitoring be expanded to monitor at least some of the more recently fenced springs.

E. OLD NILPINNA SPRING

E.1 General

Fencing in 1992 at Old Nilpinna included what was originally the main vent at the homestead ruins (vent 1 of Figure E.1), a diffuse area of seepage at Vent 2, and a third seepage west of vent, marked by a date palm in Figure E.3). The western vent responsible for the large wetland in the foreground of Figure E.1, according to local folklore, was bored as part of petroleum exploration (notes of TJ Fatchen for Getty Australia Coal Company), and temporarily "drained the spring". There was a petroleum survey in the region in 1970, but no shotlines crossed the site and there are no records of any bore being sunk at Nilpinna (PIRSA records, June 1999). Nevertheless, the notion of the spring being bored was firmly entrenched in 1985. If there was a bore placed, it is likely that local drawdown was initially responsible for diminished flows from the vent areas within the fence, and may have permitted the reduction of surface water by plant growth to have further affected the apparent flow of the fenced vent areas.

Figure E.1 Old Nilpinna springs. Photo looks roughly NE. White line is approximate division between fenced and unfenced area. *Photo SEA (1984)*



Flows from the group as a whole are strong, although the major flow is from the putative bore area. The tails from the fenced vents did not reach the fence in 1998.

The smaller-flow spring area in Old Nilpinna was fenced partly for direct protection from grazing, partly for its high richness of aquatic plants, and partly for its unusual fish fauna (SEA, 1984). Three fish species are present, including the only occurrence of the Dalhousie Catfish away from Dalhousie Springs.

Nilpinna is also unusual in having, as a consequence of early European occupation and use, both the alien date palm *Phoenix dactylifera* and the alien "bamboo" Arundo *donax.*

E.2 Condition in 1984

SEA recorded no disturbance apparent when they surveyed the group. However, they noted potential for damage by stock, on the advice of Dept of Lands officers. It would appear that the spring area was only lightly grazed at the time of their visit.

APPENDIX E
OLD NILPINNA

Figure E.2: Fenced area dimensions and photopoints

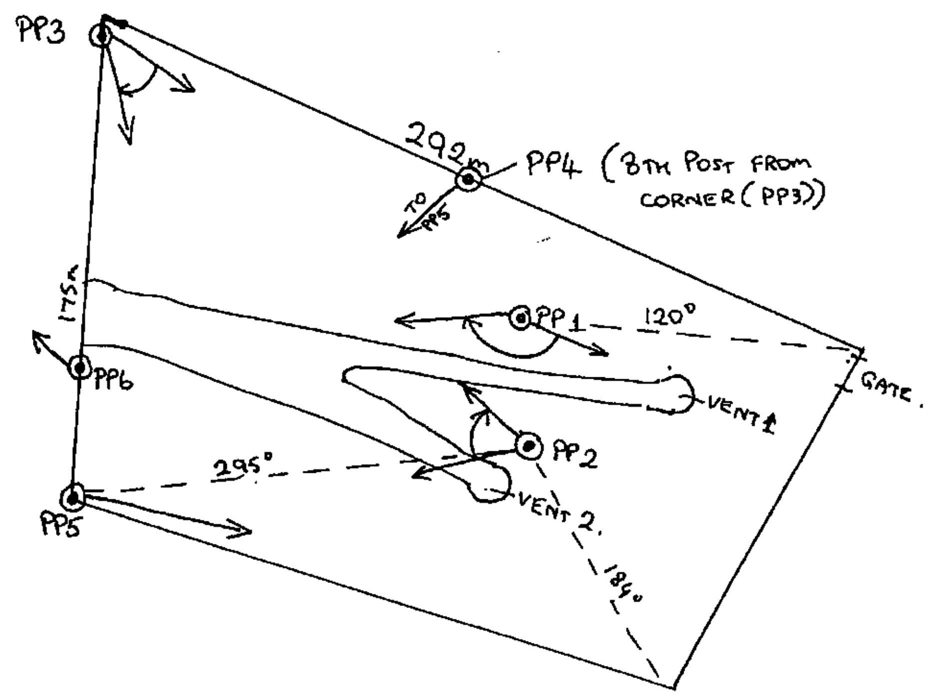


Table E.1 Wetland species, Old Nilpinna group

Wetland species	***SEA (1984)***	***1998***
Cotula coronopifolia	X	X
Cyperus gymnocaulos	X	X
Cyperus laevigatus	X	X
Halosarcia halocnemoides	X	X
Halosarcia indica	X	X
Phragmites australis	X	X
Typha sp	X	X
**Arundo donax*	X	X
**Phoenix dactylifera*	X	X
Sporobolus virginicus (possibly misidentification of *Cynodon)*	X	No
Nitraria billardieri	X	X
Enchylaena tomentosa	X	X
Schoenoplectus litoralis		X
**Spergularia rubra*		X
**Sonchus oleraceus*		X
**Cynodon dactylon*		X

E.3 Changes in incidence of plant species since fencing

There appears to have been no change in wetland species present in the group as a whole since the SEA survey: the 1998 inspection expanded the list of species (Table E.1), but the additions are annuals which may not have been present, or, in the case of *Schoenoplectus litoralis,* may not have been evident under grazing.

E.4 Expansion of wetland vegetation in fenced areas

E.4.1 Dominance and wetness changes

Other than the DEHAA photoseries, there is no reliable baseline for noting changes in Old Nilpinna wetland following fencing. From the SEA (1984) description, "Whole area is overgrown by tall bamboo and reeds", but from their photo (Figure E.1) this could not have been the case. TJ Fatchen scored that part of the spring wetland now inside the fence for cover-abundance in 1985, recording the major vent and its upper tail to be densely covered with tall bamboo, changing to a 100% cover of *Phragmites* further down the tail, with immediate surrounds mid-dense *Cyperus gymnocaulos.* Discharge from this vent (vent 1 in Figure E.2) was "strong flow". Apart from possible changes in dimensions, this was still the case in 1998.

The lower tail, from the change of slope at the base of the homestead mound, was dominated in 1985 by a 33-50% cover of *Cyperus gymnocaulos* with very scattered *Cyperus laevigatus,* on saturated soil but with no free water. By August 1998, there had been a dominance change to a 50-75% cover of *Phragmites* over most of this area. *C. gymnocaulos* appeared to have expanded on the Vent 2 area of Figure E.2. Soil conditions were damp in 1998, rather than saturated as in 1985.

Typha was recorded in 1985 only for the western spring/bore and wetland. Its presence here is circumstantial evidence of differences in water chemistry between the putative bore and the fenced spring. *Typha* was not present in 1985 in the area now fenced, and was not present in 1998.

E.4.2 DEHAA photoseries

Figures E.3 and E.4 show the following:

- After fencing 1991-92, a steady expansion of *Phragmites* at the expense of *Cyperus gymnocaulos* up to 1996
- A stabilisation in amount of *Phragmites* after 1996
- An increase in dryland or salt-marsh cover
- An increase in *Schoenoplectus litoralis* (Figure E.4 only), again to about 1996 with little change subsequently
- A short movement of bamboo down the main water channel (Figure E.3 only) but with no further migration after 1994. (The 1992 photos do not reach far enough to show its position then. The movement 1993-1994 is a matter of less than 1m).

FIGURE E.3
OLD NILPINNA
DEHAA PP2

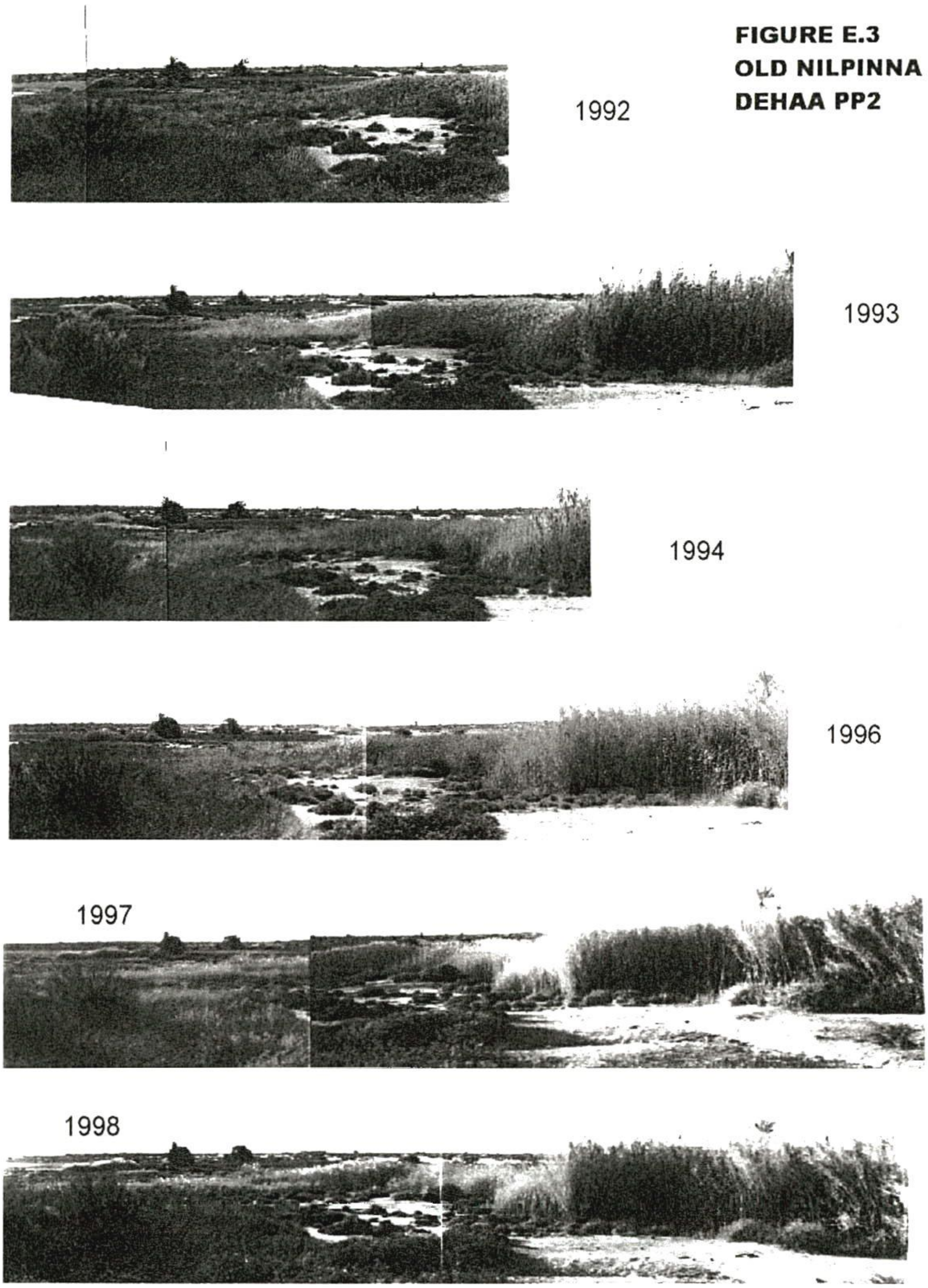
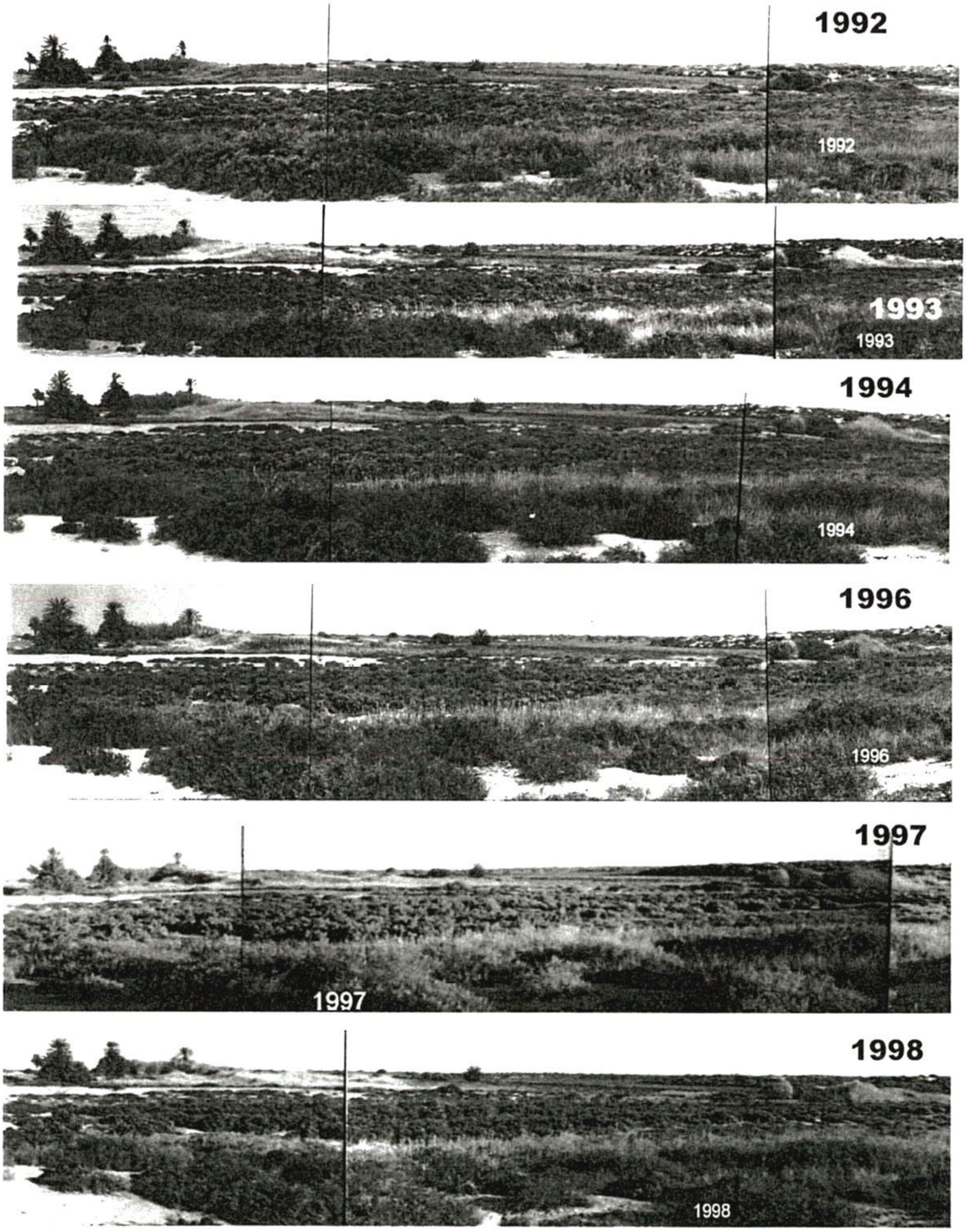


FIGURE E.4
OLD NILPINNA
DEHAA PP3



The biomass trends for the fenced area (Figure E.5), derived from all available photographs, show

- an apparent continuing trend to increased total biomass
- a levelling-off in the last two years in increases in both *Phragmites* and *Cyperus laevigatus*
- A very shallow increase in the exotic bamboo.

In contrast, the biomass trends (Figure E.6) for the grazed vent and wetland, outside the fencing, show

- Oscillation in total biomass
- Some reduction in biomass of *Phragmites*
- Oscillation or no change in *Typha* and *Cyperus gymnocaulos.*

The fencing has shifted the "inside" springs and wetland to a high-biomass state, now apparently stable. Grazing continues to maintain a dynamic balance of lower biomass outside the fencing.

E.5 Cover and plant diversity in context

Old Nilpinna has amongst the highest plant cover noted for the sampled springs (Figure A.2). There is, however, not much difference in wetland cover inside and outside the fence (Figure A.5) although the biomass is lower under grazing.

The group retains one of the highest aquatic plant species richness levels recorded for the sampled springs, remarkable for a group with so few vents (Figure A.3). There is no difference in richness inside and outside the fence (Figure A.6), though there are compositional differences, primarily the absence of *Typha* from the fenced areas (predating stock exclosure.) Cover diversity is mid-range for the whole group (Figure A.4); again, there is little difference within or outside the fence (Figure A.7).

E.6 Interpretation

The evidence suggests that the lower, unfenced spring does in fact contain a bore. The presence of *Typha* in the lower wetland only, despite flows from at least one upper vent sufficient to support it, points to water chemistry differences.

This being the case, the reduced flows from the fenced spring are likely to be a result of local drawdown. The expansion of wetland vegetation within the fenced area may have been sufficient to reduce the wetness of the associated wetland, but only to reduce it from saturated in 1985 to damp in 1998. The local reduction in wetness should pose no threat to fully aquatic and amphibious fauna, given the maintenance of a large water body by the vent/bore beyond the fencing and cattle grazing disturbance in the outside wetland.

E.7 Management issues and necessary actions

E.7.1 Vegetation management

The combination of a grazed vent/bore/wetland and an ungrazed area with less water but more biomass has, to date, resulted in a high richness spring group, with high cover diversity and high diversity in other respects, particularly the structure of the vegetation. The photographs indicate that the expansion of *Phragmites* and *Cyperus gymnocaulos* in the fenced area has stabilised, and that the exotic bamboo also is not significantly expanding.

FIGURE E.5 Old Nilpinna Lower Tail Biomass Trend

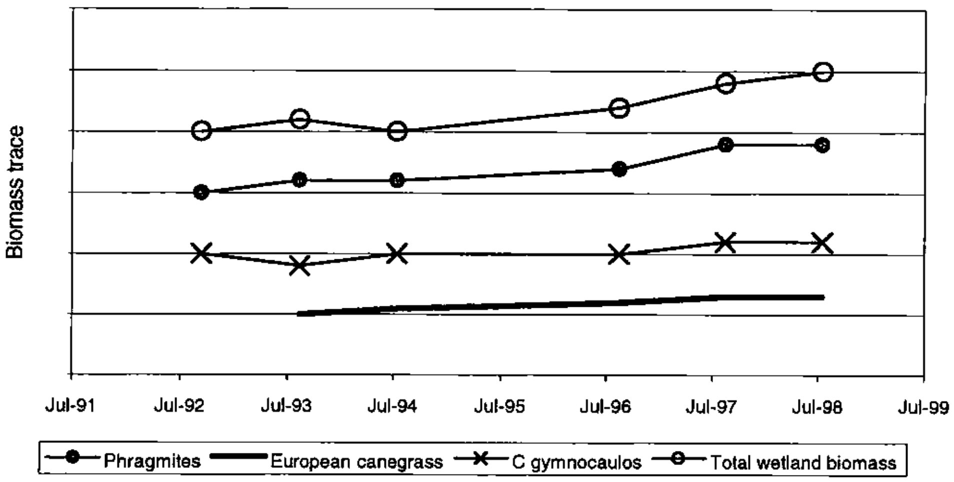
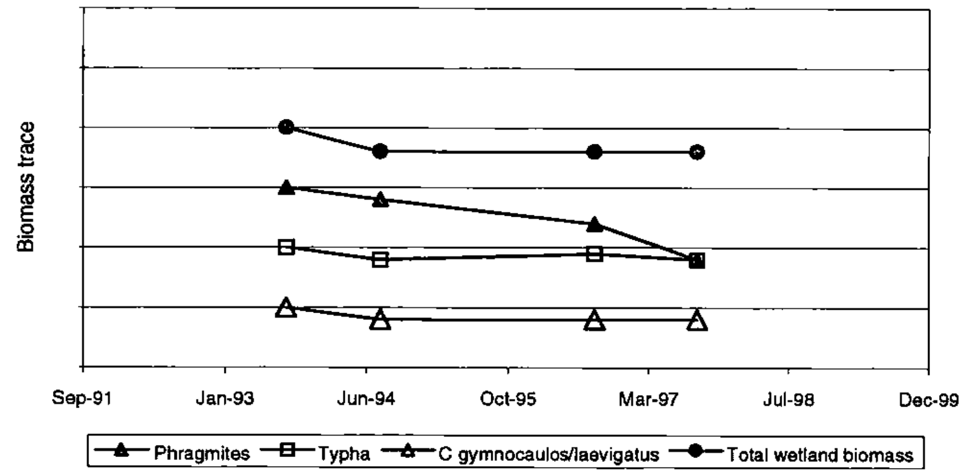


FIGURE E.6 Old Nilpinna Grazed Tail Biomass Trend



There is no urgent nor overt need to manipulate anything within this spring group, other than the alien species present, primarily bamboo and date palm. Arguments for removal of both are:

- Both species have high transpiration rates and hence water demands. There is the possibility that either or both may eventually block vents and utilise most of the supply to the disbenefit of native plants and aquatic fauna. This has occurred at the nearby Birribirriana springs.
- The bamboo is preventing the establishment of native reeds and rushes on the main upper tail of the fenced spring area and may expand to displace them totally.

Arguments for not acting are:

- Both species are part of the history of the area as relics of early European occupation.

- The artesian water supply is demonstrably adequate, even with their presence, to maintain a high richness of native species and a high cover-diversity.
- The apparent diminution of flow from the fenced spring can be ascribed to bore-sinking and the expansion of native species alone, without reference to either date palm or bamboo
- Photographs indicate that the expansion of bamboo has stopped.

On balance, an appropriate approach would be to remove seedling/sapling date palms but permit the retention of adult trees, and to reduce but not necessarily eliminate the bamboo. Both would require grubbing out, since use of fire is unlikely to destroy the dense rhizome structure of the bamboo, and cannot be confined to the bamboo areas. There is no obvious reason to further manipulate the fenced wetland by the use of fire.

E.7.2 Other issues

No other issues.

E.7.3 Management recommendations

On balance, we recommend that:

- Young individuals of date palms be removed, but that at least some adults are kept as part of the living history of the spring.
- A trial of partial removal of bamboo, using grubbing rather than fire, be attempted.
- The trial be monitored in more detail than the current photo-monitoring provides.
- The spring group otherwise be left alone, and monitoring continued.

APPENDIX F

BIG CADNA-OWIE

F. BIG CADNA-OWIE

F.1 General

Big Cadna-owie is a single vent with a strong flow, set in a travertine mound with gypseous silts covering it, with a single tail cut in the side of the mound and expanding onto a large wetland of gypseous silty clays.

Prior to fencing, the vent had a cover of mixed *Cyperus laevigatus* and *Phragmites australis* with some open-water areas. The tail, from 1984 photographs, would appear to have been a mixture of *Cyperus gymnocaulos* and *C. laevigatus* flowing through a floodplain mixture of *Atriplex nummularia* and *Halosarcia* spp.

Big Cadna-owie was recognised by SEA (1984) as having relatively low biological value, in common with most of the springs in the Mount Dutton area. It was included in their higher-ranked springs for reasons:

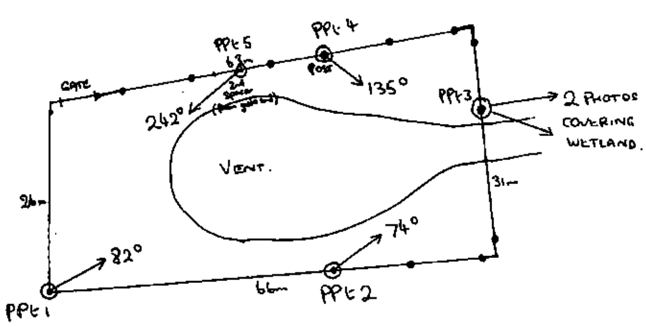
- Unusual spring form, of a single rapidly flowing spring on a moderately steep slope
- Extensive tail wetland
- Possession of an apparently local endemic hydrobiid snail (F6), albeit with similarities to a more widespread species (F5).

The spring was also significant for local pastoral use; hence the fencing undertaken in 1991 was limited to the immediate vent area (Figure F.1)

Changes influenced by the fencing have been major. They include:

- the apparent disappearance of the hydrobiid (now regarded as a local variant of the widespread species *Fonscochlea zeidleri* in Kinhill Engineers 1997, but not recently found in the spring),
- the development of a high biomass monoculture of *Phragmites* in the vent,
- breaking of the tail channel through increased stock pressures.

Figure F.1 Fenced area dimensions and photopoints



F.2 Condition prior to fencing

Figure F.2, from the SEA 1984 survey, shows the vent with a mixture of open water pools, *Cyperus laevigatus* sward and low *Phragmites.* While obviously used by cattle, it does not appear heavily pugged, although SEA recorded "much of spring severely damaged by stock". There is no information on the condition of the tail.

F.3 Changes in incidence of plant species since 1984

There appear to be significant changes in species incidence at this spring and tail since the SEA survey (Table F.1). Attention is particularly drawn to the presence in 1998 of *Acacia salicina* and *Bolboschoenus caldwellii* in the tail, and *Sporobolus virginicus* in both tail and vent, species SEA would have been unlikely to miss.

Table F.1 Plant species recorded 1984 and 1998

Species	Recorded SEA (1984)	Recorded August 1998
Wetland or associated species		
Acacia salicina		X
Bolboschoenus caldwellii		X
Chara sp.	X	X
Cyperus gymnocaulos	X	X
Cyperus laevigatus	X	X
Halosarcia indica	X	X
Phragmites australis	X	X
Potamogeton pectinata		X
**Spergularia rubra*		X
Sporobolus virginicus		X
Dryland species		
Acacia ligulata	X	X
Atriplex spongiosa	X	Several annual Atriplex spp.
Enchylaena tomentosa	X	X
Nitraria billardierei	X	X
Trigonella sp		X

These additions may be simply cyclic appearances, caught in 1998 but not present in 1984. They may, however be linked to drying of the area (*Acacia salicina, Sporobolus virginicus*) or water chemistry changes (*Bolboschoenus)* which in turn may be influenced by changes occurring in the closely-fenced vent.

F.4 Wetland expansion and reduction

F.4.1 Expansion of **Phragmites** *within the fenced vent*

Monitoring photos were not taken prior to fencing, and could not be taken for some time after fencing was completed. By 1992, the first available photo, *Phragmites* had already displaced all other species from the wet vent (Figure F.3). The only readily visible difference by 1998 was that biomass of *Phragmites* had increased further. In contrast, *Phragmites* outside the fenced area, in the upper, channelled tail, has been kept at low biomass levels over the same period (Figures F.4, F.5). Given that cattle use of the upper tail is likely to be heavier than prior to stock exclusion from the vent, *Phragmites* biomass may be lower than prior to fencing.

Biomass trends on the vent are estimated in Figure F.6. Different photopoints yield equivalent traces. Biomass appears to have peaked in 1995, four years after fencing, and has since oscillated.

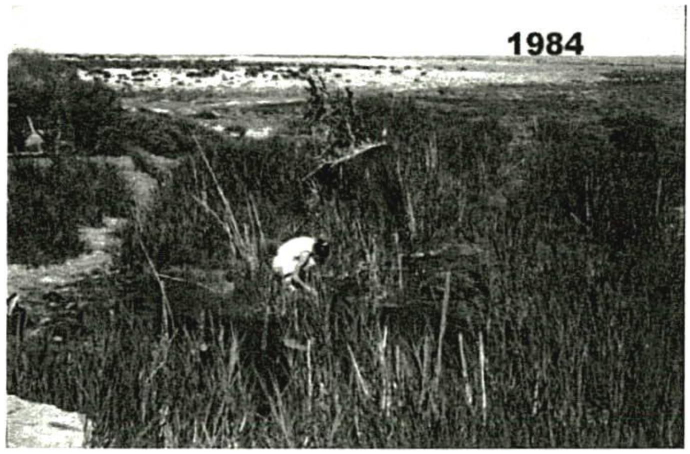


FIGURE F.2
BIG CADNA-OWIE
VENT 1984

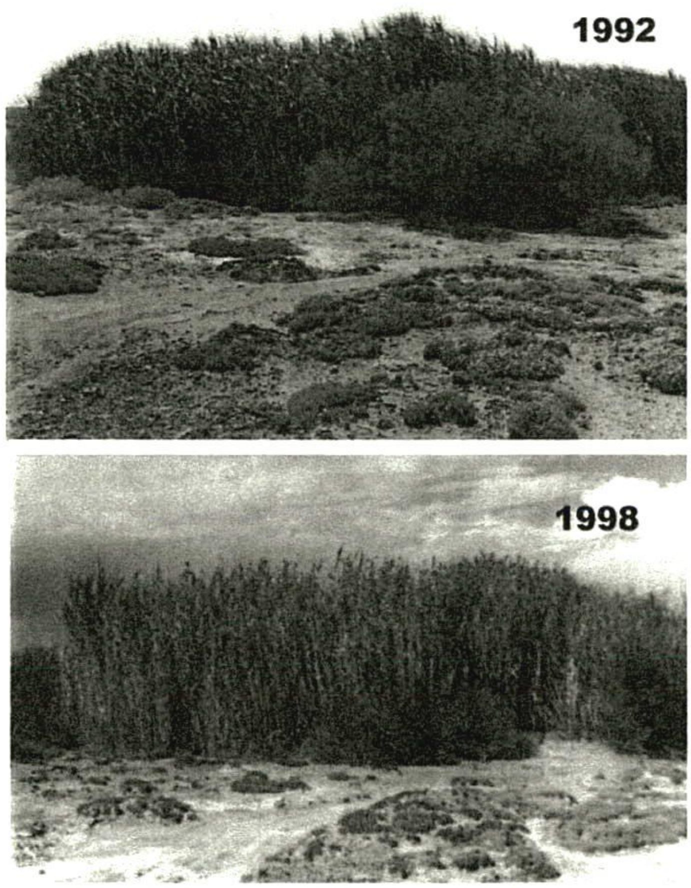


FIGURE F.3
BIG CADNA-OWIE
VENT FENCED

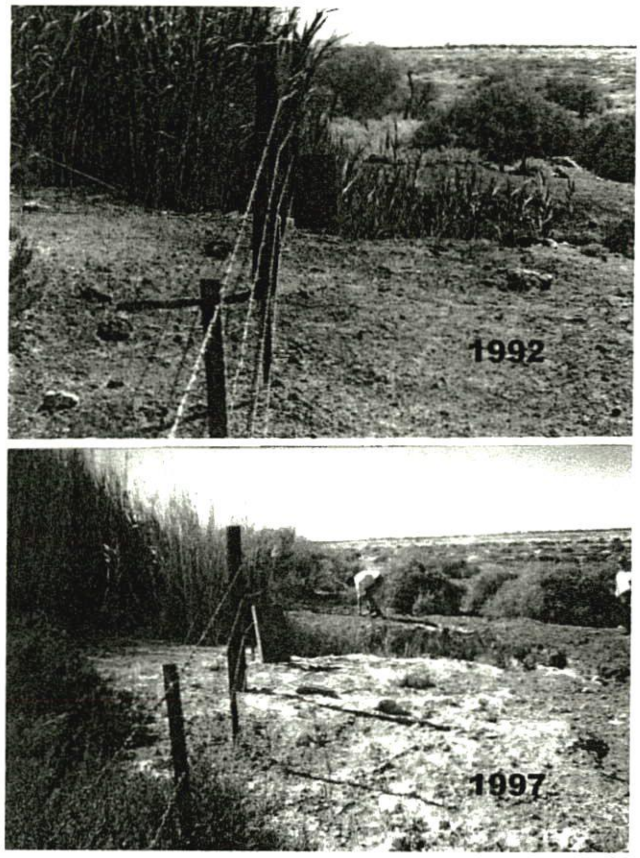


FIGURE F.4
PHRAGMITES
HELD AT FENCE
BY GRAZING

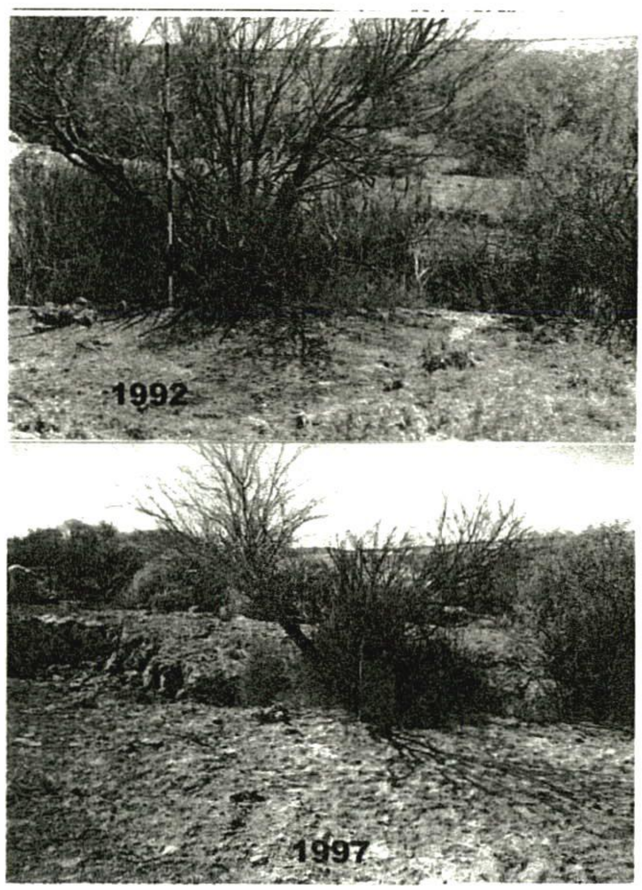
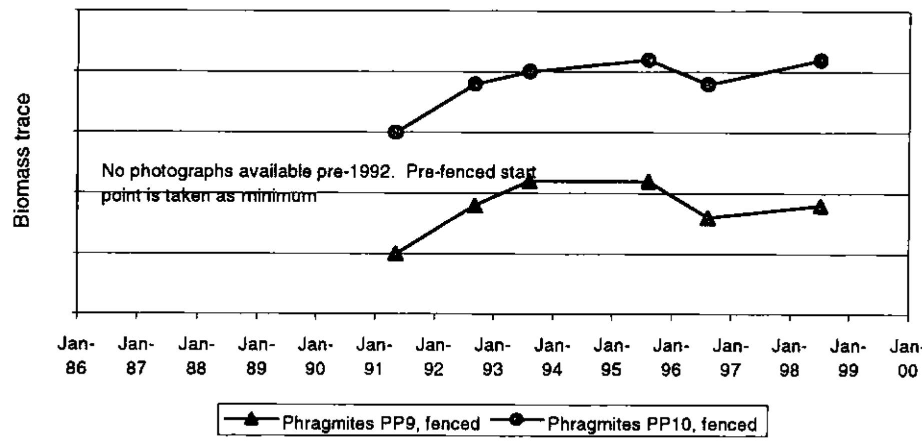


FIGURE F5
BIG CADNA-OWIE
UPPER TAIL GUTTER

FIGURE F.6 Big Cadna-Owie PPs 9, 10 (fenced)
***Phragmites* biomass Trend**



F.4.2 Physical damage to upper tail by stock

It is evident in Figures F.4 and F.5 that the unfenced upper tail channel is under heavy stock pressure. The main effect of stock, apart from limiting growth of any sort, but particularly the expansion of *Phragmites*, is the breaking down of the channel edges.

F.4.3 Apparent contractions in the lower tail

The path taken by flows on the nearly level lower tail is affected by stock pugging. This would usually mean that flows would regularly be redirected, but that in the long term a mixture of wetland and dryland (floodplain) vegetation would be supported. Hence one would expect to find semi-aquatic species, particularly *C. gymnocaulos* which is tolerant of long periods of dryness, established and live on all areas regularly reached even by intermittent flows.

The main cover of the vegetated tail is *Cyperus gymnocaulos,* which is tuberous. On the margins of the current wetland, there are extensive areas of dead *C. gymnocaulos* tubers, indicating a long-term cessation of flow and in turn implying a contraction of the wetland.

F.5 Cover and plant diversity in context

For the spring and tail combined, Big Cadna-owie is one of the higher species richness and cover diversity groups, despite there being only one vent. (Figure A.3, A.4). However, most of this is contributed by the tail. Within the fenced area, the vent has the highest plant cover of any spring examined. The fenced cover is almost double that outside the fence (Figure A.5), while species richness and cover diversity inside the fence is minimal compared to outside the fence (Figures A.6, A.7).

F.6 Interpretation

In essence, the fencing of Big Cadna-owie has delivered a high biomass - low diversity return, with the vent wetland occupied by a zero-diversity stand of *Phragmites*. Fencing has increased damage to the mound by concentrating stock water usage in the "fresh" water in the upper, channelled tail. It also may have contributed to the apparent disappearance of the local hydrobiid snail and may be contributing to the apparent contraction of the tail wetland.

The hydrobiid, originally thought to be a local endemic, is understood to be a local variant of the otherwise widespread *Fonscochlea zeidleri*, but with the local population showing considerable differences in morphology. Hence while not having species status, the local population nevertheless demonstrated speciation in process. It has not been found in the recent WMC-sponsored invertebrate surveys.

It is known that hydrobiids respond to very dense *Phragmites* cover by moving to the margins of springs or to the tails. In the present case, the spring has no margin to move to, and the upper tail, with suitable habitat, is heavily impacted by cattle. A possible scenario is that the hydrobiid was forced from the vent by the *Phragmites* growth, to be eliminated from the tail by heavy cattle use.

The *Phragmites* is now of sufficient age, height and biomass to have generated a dense rhizomatous mat, noted in the Hermit Hill region to have actually capped vents (Fatchen and Fatchen 1993). There may be reduced spring flows therefore, and this may be a factor in the apparent reduction of the tail wetland. (Transpiration losses from the *Phragmites* alone would not be sufficient to reduce flows in a strongly-flowing spring of this size.)

F.7 Management issues and necessary actions

F.7.1 Vegetation management on the fenced vent

There is a strong case for manipulating the vent vegetation for purposes:

- Increasing the plant diversity of the vent
- Possibly recovering hydrobiid populations, assuming individuals are still present at low density
- Potentially increasing flows and permitting enlargement of the wetland.

All entail reduction of *Phragmites* biomass and at least partial break-up of any *Phragmites* rhizome caps. All are based on the model derived from the Hermit Hill area: the requirement to eliminate the competitive advantage of *Phragmites*, reduce vent capping and reduce transpiration loads (a minor concern in this case).

Mechanisms available are:

- Re-introduction of stock by removal of the fence
- Fire
- Mechanical disturbance

Neither re-introduction of stock nor fire is considered viable in this situation, in both cases because of the possibility of there surviving a remnant hydrobiid population.

In the case of stock re-introduction, it is possible that the breakdown and pugging which would initially occur in the reedbed could wipe out any remnant hydrobiid population before sufficient habitat mosaics were created for its continuation.

Firing is likely to burn down the fence, as occurred at Emerald Spring at some time before 1997/98. This in turn would result *de facto* in re-introduction of stock on top of the impact of burning, as also occurred, eventually, at Emerald. However, it also would appear that burning of Emerald, at a stage when stocking pressures in the Emerald tail had been high, contributed to the recent disappearance of hydrobiids from that spring. The situation and mechanism we suggest is directly homologous to Big Cadna-owie:

- A single vent with no other vents nearby which might allow later recolonisation.

- Major and dense reed growth forcing hydrobiids to the wet margins of the vent and into the upper tail. In a confined crater, as at Emerald and Big Cadna-owie, there are no wet margins other than at the interface between vent and upper tail.
- Very heavy stock impacts in the upper tail reducing hydrobiid populations to a small remnant on the vent/tail interface.
- Firing of the vent reedbed eliminating this last population, either directly, or by water heated beyond the population's tolerance, or by water chemistry changes from ash.

Mechanical disturbance can be applied without the risks inherent in either of the preceding, if simple appliances such as brushcutters and mattocks are used, and heavy earthmoving machinery avoided.

F.7.2 Vegetation management on the tail

Extending the fencing does not appear to be a viable option. It is clear that only the current grazing is holding expansion of *Phragmites* from the upper tail, and that this too would develop to a monoculture if released from grazing. Further, extension of the fenced area may well result in a further-reduced tail wetland, as *Phragmites* dams the upper tail as well as partly blocking the vent.

The fact that the water supply from the spring is an integral part of local pastoral operation does not play any part in questions of extending the fence. There are means which could be applied, even with enlarged fencing, to provide stock water. These include reversion to the 19th C operation of gravity-fed flow to a trough away from the spring.

The desirable outcome would be to maintain enough grazing pressure on the tail to keep *Phragmites* at its present low level, without further contributing to stock breaking the slopes of the upper tail channel. This could possibly be achieved by piping some of the water away from the tail, but again, this is likely to result in further tail contraction.

F.7.3 Management recommendations

On balance, we recommend that:

- A trial be undertaken of reduction of *Phragmites* within the fenced areas by manual cutting and grubbing, for purposes of testing
    - whether the spring flow can be increased with partial removal of *Phragmites*
    - whether a local hydrobiid population remains and is capable of recovery given the habitat manipulation.
- Prior to the trial, necessary baselines be established, including
    - Documentation of the present extent of the tail wetland
    - Establishment of current flow rates from the spring
    - A further targeted search for survivors of the hydrobiid population.
- The trial itself be subject to care in design and implementation, and subsequent monitoring in detail.

APPENDIX G
BIG PERRY

G. BIG PERRY

G.1 General

Big Perry is a large silty gypseous mound, with relatively strong flow from two major vents, and with a third damp seep present. The fenced area encloses the mound (Figure G.1), the vents and most of the tail areas.

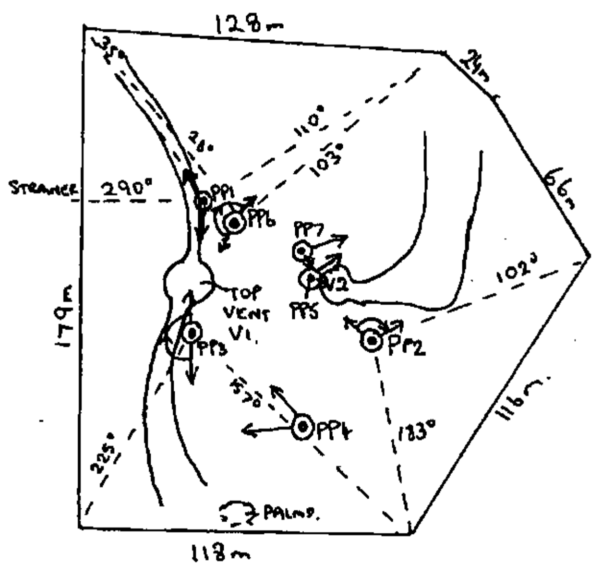
There has been major reed growth on vents since fencing. Areas of open water have reduced and plant cover expanded significantly on tails. The smallest vent, now only slightly damp, had at least free water present in 1984 (SEA 1984).

There appear to be either flow or water chemistry differences, or both, on the two major vents, reflected in the current dominance of one by *Phragmites* and of the other by *Typha.*

The biological significance of Big Perry lies with its invertebrate fauna. The hydrobiid fauna of Big Perry comprises the widespread *Fonscochlea zeidleri* and *F. aquatica,* the less widespread *Trochidrobia smithii,* and the very restricted species *Fonscochlea expandolabra* and *Trochidrobia minuta.* The latter two species are largely restricted to the Neales River spring complex, with occurrences at Freeling Springs: each has been recorded in only six spring groups, of which Big Perry, Outside, The Fountain and Twelve Mile are all small groups with few vents.

Accordingly, maintenance of flows from the three vents at Big Perry is of some concern, and manipulation of vegetation may be necessary both to ensure flows are maintained and to keep some relatively open water areas for hydrobiid habitat. All species have recently been re-recorded at the springs as part of the Lake Eyre South Study (Tapp and Niejalke 1998), but there is no information on the degree of displacement due to expansion of vegetation post-fencing.

Figure G.1 Fenced area dimensions and photopoints



G.2 Condition prior to fencing

SEA (1984) reported little vegetation on the tails of springs, with some pugging. Photographic records indicate the springs were under heavy stock impact when fenced in 1984.

G.3 Changes in incidence of plant species since fencing

Semi-aquatic and associated species recorded by SEA (1984) are listed in Table G.1. Two species were missing in the August 1998 field inspection. *Juncus krausii* may still be present but obscured by reeds, but the apparent absence of *Schoenoplectus litoralis* may be a response to expansion of other semi-aquatics and an indicator of reduced open water habitat.

Acacia salicina, not recorded by SEA, has established on the lower tails.

Table G.1 Semi-aquatic or spring-dependent plant species, Big Perry

Species	*SEA (1984)*	*Recorded August 1998*
Cyperus gymnocaulos	X	X
Cyperus laevigatus	X	X
Halosarcia indica	X	X
Juncus krausii	X	Not recorded, may be obscured by reed growth
*Phoenix dactylifera	X	X
Phragmites australis	X	X
Schoenoplectus litoralis	X	Not recorded
Typha domingensis	X	X

G.4 Expansion of wetland vegetation in fenced springs

G.4.1 Dominance and wetness changes

From the SEA reports and data sheets, vegetation was sparse and no species could be said to be dominating the vents. The small vent located near PP6 in Figure G.1 was apparently flowing at the time of the SEA survey. It has recently become almost extinct: the area retains a halo of abundant *Cyperus gymnocaulos* (20% cover) around the now bare, black silty former vent. A tail of sorts, of hayed-off *Typha*, extends for some 25 m from the former vent.

For the two major vents, there has been a major increase in vegetation. Figure G.2 summarises changes at Vent 1, with the full photo series given in Figure G.3. The original vent area has an almost total cover of *Phragmites* to 3.5m. The main tail runs southerly, however new short secondary tails, dominated by *Cyperus gymnocaulos*, are forming to the north of the original vent.

Part way down the main southern tail, and occupying most of the foreground of the later photos in Figure G.3, the *Phragmites* cover reduces without any change in height and *Cyperus gymnocaulos* is abundant as a secondary component. Toward the change of slope, *Phragmites* is replaced by *Typha* as the dominant. At the base of the mound, the wetland spreads into still water areas with a 50-75% cover of *Cyperus gymnocaulos*. Free water no longer reaches the fence or the date palm near the fence within the exclosure.

Biomass trends for this area (Figure G.5) suggest a continuous increase to 1996, with an apparent stabilisation since. On this basis, the plant growth may now be in balance with the water supply, but the levelling-off shown by the biomass trend plot is too short to offer any certainty. The available free water may well continue to reduce in this tail.

FIGURE G.2
BIG PERRY
VENT 1

Under grazing

1984

At time of fencing

Current

1998

FIGURE G.3
BIG PERRY
PHOTO SEQUENCE VENT 1
1991-1998

FIGURE G.4
BIG PERRY
EXPANSION OF BIOMASS ON TAIL

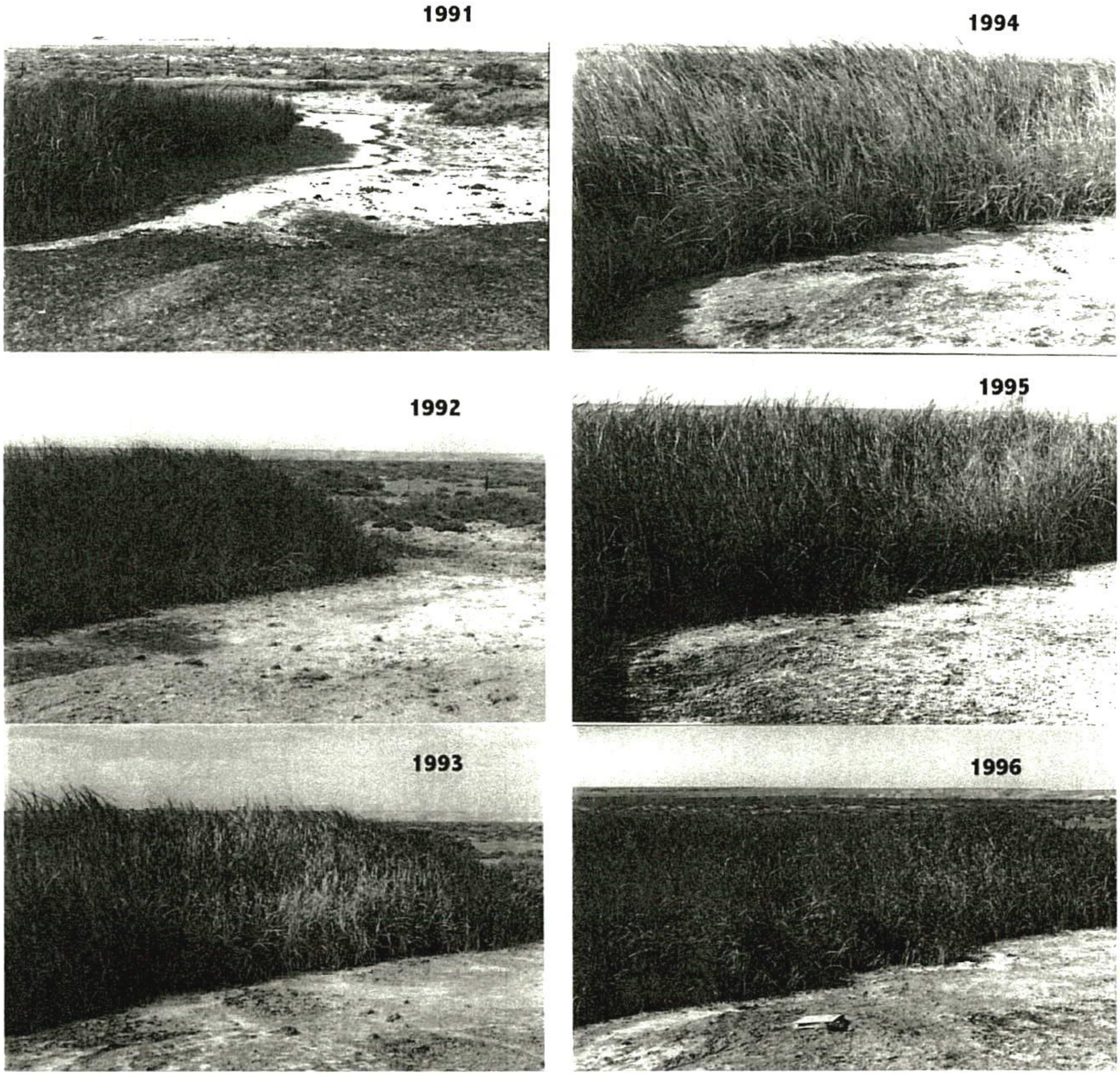


FIGURE G.5 Big Perry PP1 Biomass Trend

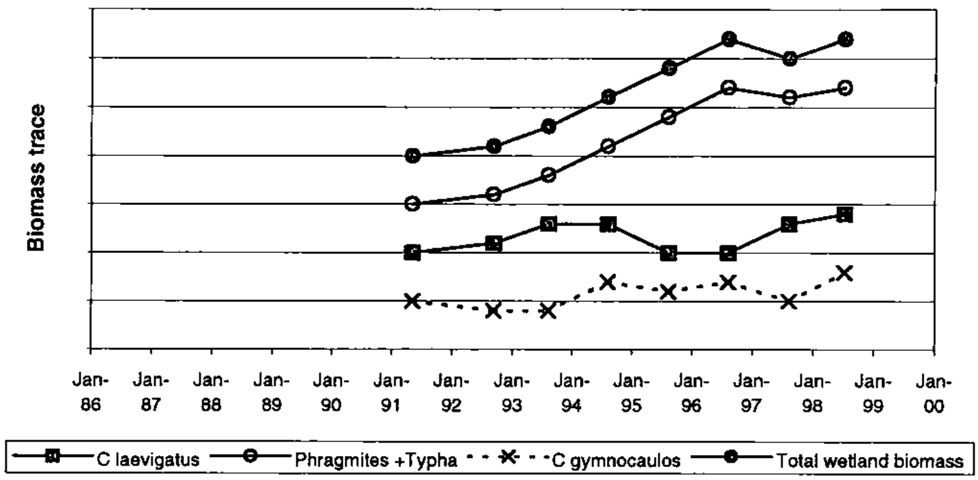
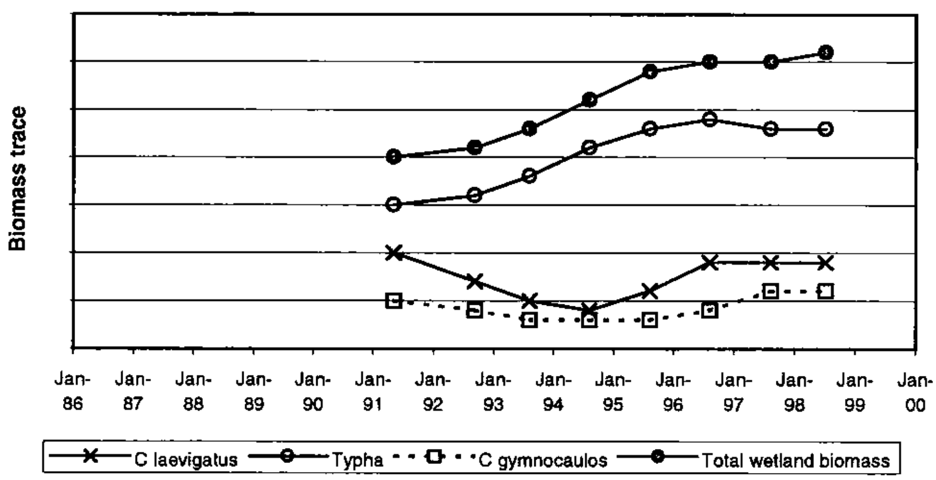


FIGURE G.6 Big Perry PP2 Biomass Trend



Vent 2 is dominated by an almost complete cover of *Typha*, to 2.2m high, with scattered *Cyperus gymnocaulos* on the edge of the *Typha*. The *Typha* appears to be continuing to migrate down the tail. The photoseries for the middle portion of the tail (Figure G.4) and the biomass trends determined from it (Figure G.6) indicate a levelling off simply because the *Typha* has fully occupied the entire tail within the photo field. Beyond the *Typha*, the tail has an open cover of *Cyperus gymnocaulos*.

G.5 Cover and plant diversity in context

The fenced group at Big Perry has mid-range plant cover, species richness and cover diversity compared with other fenced springs (Figures A.2, A.3, A.4). Cover is much higher than in unfenced areas. However, it is distinguished from most of the other fenced springs by the degree to which vegetation is zoned down the mound slope, particularly the change in the tail of Vent 1 from *Phragmites*, to *Typha*, to *Cyperus gymnocaulos.*

G.6 Management issues and necessary actions

G.6.1 Vegetation management

The most important aspect of the vegetation change relates to hydrobiid habitat. What would have been flowing water areas with little plant cover, down the slopes of the mound, is now impeded flow with tall and dense reed or bulrush cover. As well, the still water areas at the base of the mound appear to be contracting. Further, water demand is such that one minor vent is now extinct. Depending on where the hydrobiid populations are, there is a case for manipulation of the *Typha* and *Phragmites.*

The concern is that there are only two functioning vents, each with a differing dominant plant. This does not allow room for a trial and error approach. If fire, mechanical manipulation or intermittent stocking is applied to reduce the reedbeds, and is not the most appropriate technique, the attempted manipulation may adversely affect the aquatic fauna.

There is opportunity for a trial of firing the *Typha* associated with the third, currently extinct vent. This however carries risks of also accidentally firing the other vents, which are close.

On balance, Big Perry does not offer a safe environment for testing possible manipulations of the wetland vegetation. The indications are that some reduction of reedbeds may be needed to maintain even the present wetlands, but the trials to test methods should be applied elsewhere, not in this group. In the interim, more information is required on the response of the aquatic fauna to the major changes in the vegetation and flow patterns.

As for Old Nilpinna, the presence of date palms is part of European history of the area. The palm has a high transpiration rate and hence water demand. However, it is unlikely to interfere with flows from vents given its location near the end of a tail. Provided there is no spread away from the present location, it is unlikely to impinge on the native vegetation or the flow from the vents.

G.6.2 Management recommendations

We recommend that:

- Monitoring of Big Perry should be specifically targeted at establishing whether the expansion of reedbeds has in fact halted, and whether the wetland areas have stabilised or are reducing.
- Manipulation of the vegetation should be considered for the near future (2-4 years) if monitoring indicates a continued increase in reedbeds or a drying of current tails.
- Manipulation of vegetation at Big Perry should only be undertaken once trials *elsewhere* have demonstrated the validity and limitations of the manipulation options
- More information should be sought on the present distributions of hydrobiids within the spring, before deciding on what form manipulation of the vegetation might take.
- Any young individuals of date palms be removed, but that the adult tree be kept as part of the living history of the spring.

APPENDIX H
TARLTON

H. TARLTON

H.1 General

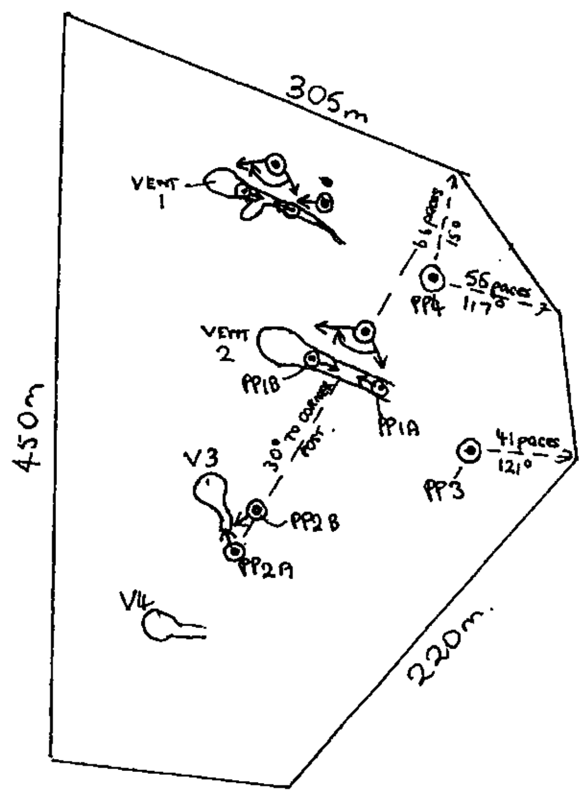
Tarlton spring group is a series of vents along a fault line on the eastern base of Mt Margaret. The fenced area contains the main group of vents (Figure H.1). There are 5-7 vents depending on definition, with tails merging in several cases.

The vents when fenced in 1988 had small flows, with free water present. There is no formal record other than the photographs. Vents had grazed *Typha* present on the actual seepages, with tails of *Cyperus laevigatus*, **Spergularia rubra* and *Cyperus gymnocaulos*. The four species are the total of the semi aquatic flora: live *Cyperus laevigatus* was not present in August 1998.

In 1998, all vent and tail areas save one were totally dominated by *Typha*, with free water rarely found. The exception was dominated by *Cyperus gymnocaulos* on a damp area.

The widespread ostracod is the only aquatic invertebrate recorded for the group.

Figure H.1 Tarlton Spring group (fully fenced)



H.2 Expansion of wetland vegetation in fenced areas

Since fencing, *Typha* has expanded on all vents, to a maximum about 1994-1995. Subsequently, with vents either capped or all water from vents being transpired by *Typha,* there has been a reduction in *Typha* extent. An exception is a small, apparently new vent adjoining Vent 3 of Figure H.1; where free water is present on vent edges and *Typha* is locally expanding.

The extent of the *Typha* expansion is clearly shown in Figures H.2 and H.3.

Typha development on vent 3 is shown in Figures H.4 and H.5, and on its tail in Figure H.6. Biomass trends have been roughly scaled in these cases, using cover-abundance data from the 1998 survey to allow an indication of absolute values rather than relative trends.

From Figure H.4, a rapid increase in *Typha* biomass, some fourfold, took place between 1988 and 1994, followed by a reduction to 1998. Over the same period, *Cyperus laevigatus* was eliminated, and *C. gymnocaulos* appeared in small quantities. The biomass trend for the whole wetland, derived from photos only, was an increase to a peak in 1997 (Figure H.5).

In the originally damp tail, a pugged cover of *Spergularia rubra* was replaced by both *Typha* and *C. gymnocaulos* (Figure H.6). Both the latter increased to 1992, at which point the *Typha* outcompeted the *C. gymnocaulos* to peak in 1993. After 1993, the increased biomass and transpiration load on the vent limited the water supply to the tail, and *Typha* declined, eventually to zero. *C. gymnocaulos,* with a much lower water demand, increased as *Typha* declined and was dominating the faintly damp tail in 1998.

The variation is a very good illustration of *Typha* expanding to beyond the limits of the water supply, and subsequently contracting to the vent. This is a case where transpiration and spring supply are in balance: the vent is still supplying water, but there is no surface manifestation.

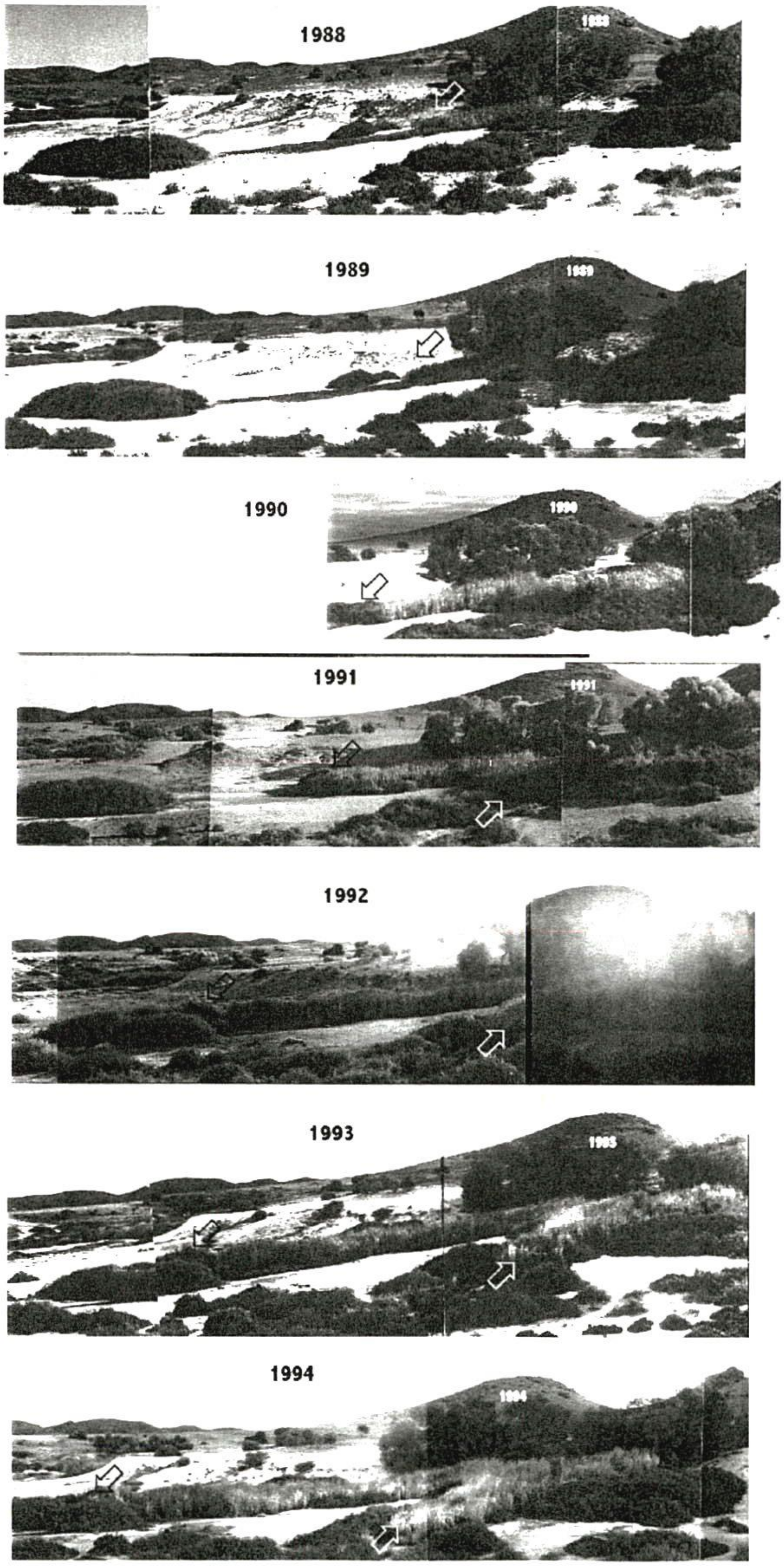
H.3 Cover and plant diversity in context

In terms of cover on vents, Tarlton is one of the three most densely covered spring groups within the fenced springs (Figure A.2). Its aquatic plant richness and cover diversity are low (Figures A.3, A.4).

H.4 Interpretation

The absence of significant aquatic fauna, the existence of several equivalent vents and tails within close proximity, and the simplicity of the vegetation, make Tarlton an appropriate area to run trials of spring vegetation manipulation in a relatively controlled manner.

In particular, it is a relatively safe environment for testing the effect of firing on *Typha*-dominated springs. Detailed design is required, but the basic hypothesis for testing is that burning of a dense *Typha* cover will result in increased flow from the burnt vent, and an increase in semi-aquatic plant and cover diversity. This is simply tested without necessity for complex design: either an apparently non-flowing spring can be made to flow on the surface by burning, or it cannot. Natural fluctuations in flow can be monitored on adjoining, equivalent, unburnt springs.



Arrows show limits of Typha

FIGURE H.2 TARLTON 1988-1994

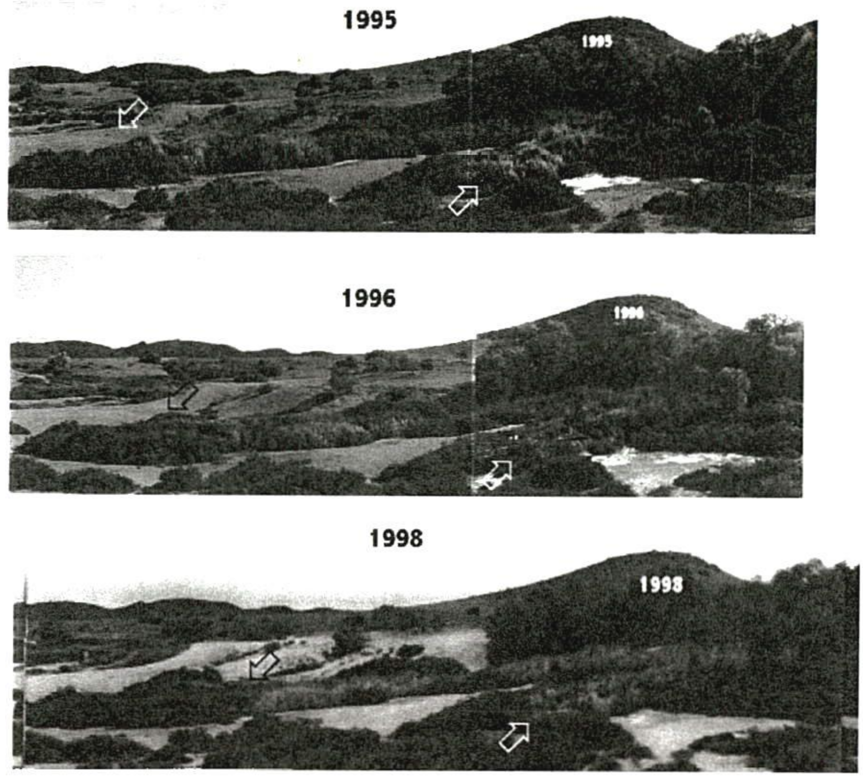


FIGURE H.3 TARLTON 1995-1998

FIGURE H.4 Tarlton ATSv3 PP2a
Scaled biomass trend
(photointerpretation matched with 1998 field data)

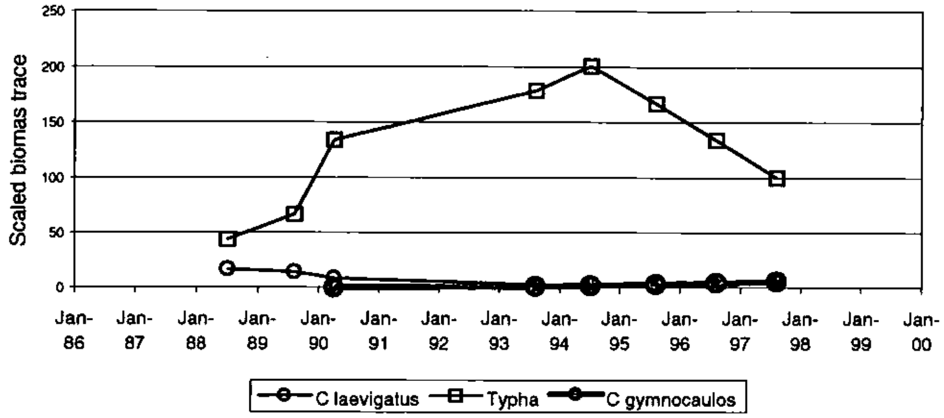


FIGURE H.5 Tarlton ATSv3 PP2a
Total wetland biomass trend

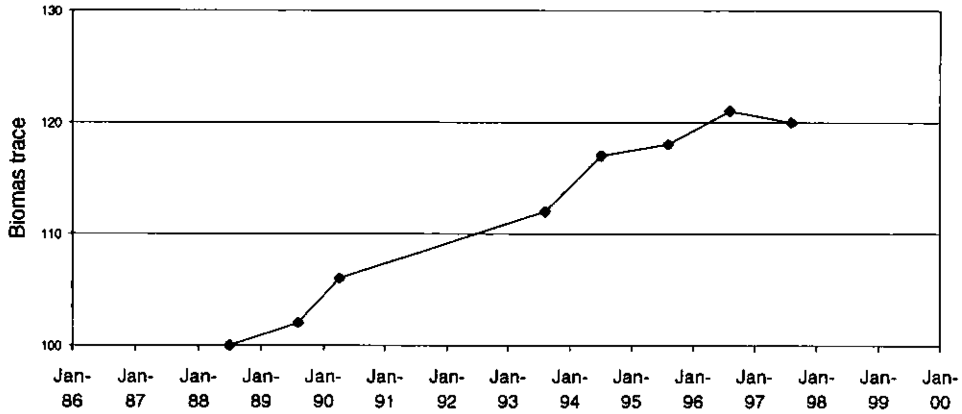
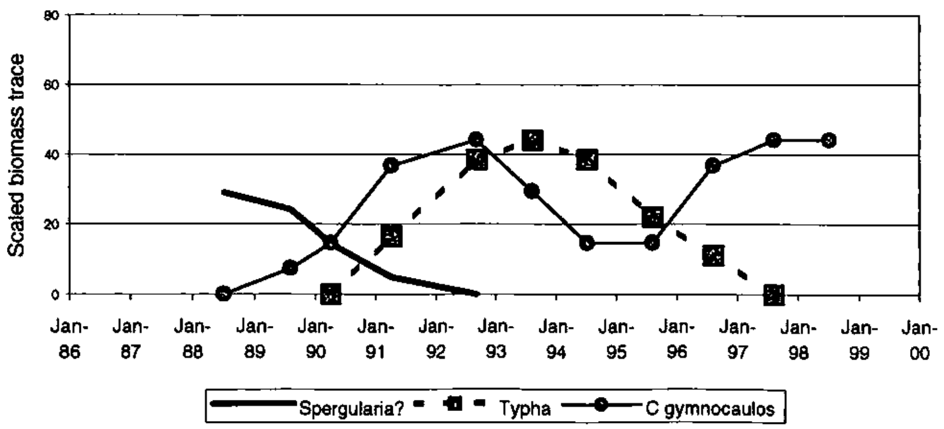


FIGURE H.6 Tarlton ATSv3 Tail PP2b
Scaled biomass trend
(photointerpretation and 1998 field data)



H.5 Management issues and necessary actions

There are no pressing reasons for management actions at Tarlton other than manipulations to re-start surface flows. These should be undertaken as a designed, fully documented and monitored trial. In particular, we recommend that:

- The use of fire as a management tool in *Typha* be tested in the northern spring "wetland" at Tarlton, using the other springs as controls.
- The trial be appropriately designed, with pre-burning measurement, direct recording of the burning operation, and rigorous monitoring of the outcome.

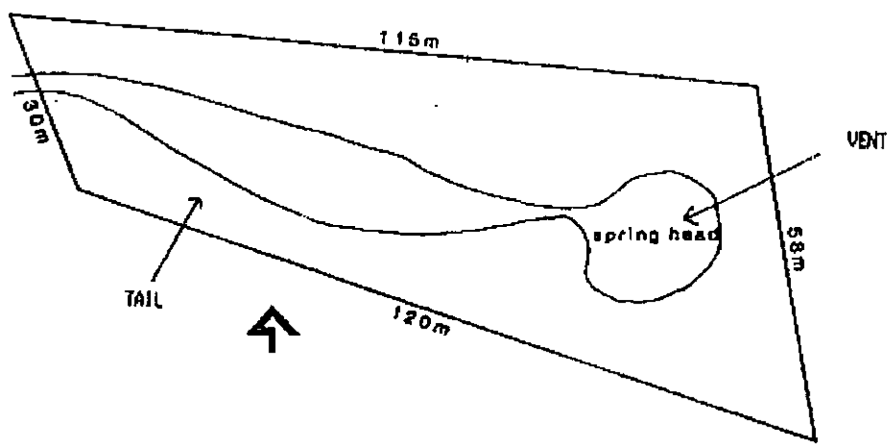
APPENDIX I
THE FOUNTAIN

I. THE FOUNTAIN

I.1 General

The Fountain group comprises a single isolated vent, set in a limestone mound with a gypseous silty cover. The vent itself was a small, shallow pool, 10-15m in diameter (SEA 1984), with a strong flow into a long narrow tail through a break in the pool rim (Figure I.1).

Figure I.1 The Fountain fenced area dimensions and photopoints



The Fountain was fenced in 1988, although monitoring runs do not start until 1989. In May 1991, cattle broke into the exclosure, with "ten cattle perishing after breaking into The Fountain and becoming trapped within the exclosure, devastating the spring in the process." (Harris 1992). With the installation of one-way gates, there have been no further stock incursions. However, stock hang about the perimeter of the fencing and, especially, impose heavy grazing and pugging on the part of the lower tail outside the spring fence.

The semi-aquatic flora is depauperate and was so prior to fencing. *Phragmites* has expanded since fencing to fill the original vent and extend over most of the surface of the mound and the mound edges, creating a zero-diversity vegetated wetland. It has not yet successfully invaded the lower tail within the fenced area. Some is present in the lower tail outside the fenced area, but is held by stock grazing.

The Fountain has a significant hydrobiid fauna, comprising the widespread *Fonscochlea zeidleri* and *F. aquatica*, the less widespread *Trochidrobia smithii*, and the very restricted species *Fonscochlea expandolabra* and *Trochidrobia minuta*. The latter two species have been recorded in only six spring groups, of which four including The Fountain are small groups with few vents.

As with the similar situations in Big Perry, Outside and Twelve Mile springs, maintenance of the flow from the single vent, and maintenance of at least some cover other than *Phragmites* is necessary for the maintenance of the hydrobiid populations. All species have recently been re-recorded at the springs as part of the Lake Eyre South Study (Tapp and Niejalke 1998), but there is no information on the degree of displacement due to expansion of vegetation post-fencing.

I.2 Condition prior to fencing

Both Symon (1985) and SEA (1984) report evidence of heavy pugging and infill of the vent by cattle.

I.3 Changes in incidence of plant species since fencing

No new invasions of plant species have occurred since fencing. The semi-aquatic species present, recorded by Symon, SEA and in 1998 field inspection, are *Phragmites australis, Cyperus laevigatus, C. gymnocaulos, *Spergularia rubra*. The alien **Polypogon monspeliensis*, recorded in earlier surveys, was not present in 1998.

I.4 Expansion of wetland vegetation in fenced areas

I.4.1 Development of **Phragmites** *monoculture on The Fountain vent*

The major change since release from stocking has been the major expansion and growth of *Phragmites* on the vent and the uppermost tail areas. (Figure I.2). A monoculture has developed, with the formerly present *Cyperus laevigatus* and *C. gymnocaulos* displaced and now found only in the tail. The "devastation" by stock trapped in the spring in 1991 has had no perceptible effect on this expansion.

I.4.2 Biomass changes and invasions on The Fountain tail

In the narrow tail, *Phragmites* has over the same period established only on the steeper mound slope and at the perimeter fence. The fenced tail has developed a low *Cyperus laevigatus* sward fringed with *C. gymnocaulos* (Figure I.3). Biomass trends (Figure I.4) from the photo series, which commences well *after* fencing was completed, show the following:

- A reduction in all species and in total biomass in 1991, a consequence of stock being present and heavily grazing and pugging the tail
- A subsequent increase in *C. laevigatus* biomass to a plateau maintained from 1993 onwards
- A post-1991 increase in *C . gymnocaulos* to the present, with some oscillation
- A shift from *Cyperus laevigatus* dominance prior to 1998 to *C. gymnocaulos* dominance in 1998.
- Establishment of *Phragmites australis* in 1991, peaking initially in 1994 with an increase since 1996
- Total biomass oscillating about a plateau since 1993.

I.4.3 Possible flow reductions

We would expect the flow from the spring to have been altered by the expansion of *Phragmites*, but there is no reliable data to test this. The change to *Cyperus gymnocaulos* dominance in the tail is certainly suggestive of significantly reduced flows and possibly of flow-related water quality changes. The single moderate outflow in a well-defined channel is readily amenable to simple weir gauging.

I.5 Cover and plant diversity in context

Plant cover, mainly *Phragmites*, on The Fountain is high relative to other fenced springs (Figure A.2). Species richness and cover diversity is relatively low.

FIGURE I.2
THE FOUNTAIN VENT AND UPPER TAIL

1992

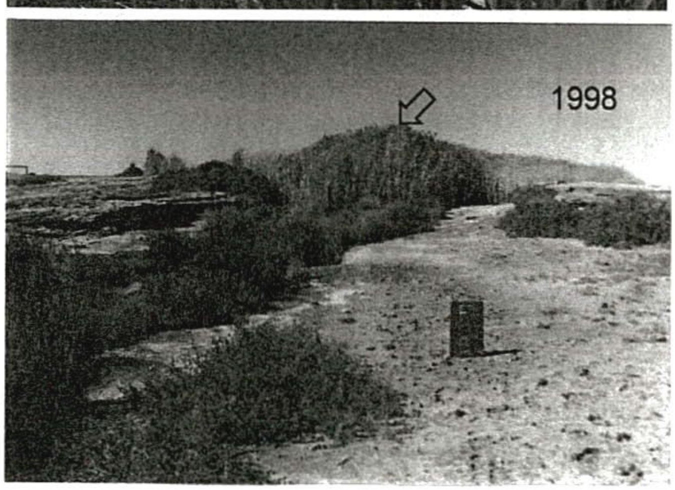


FIGURE I.3
THE FOUNTAIN LOWER TAIL

1989

1993

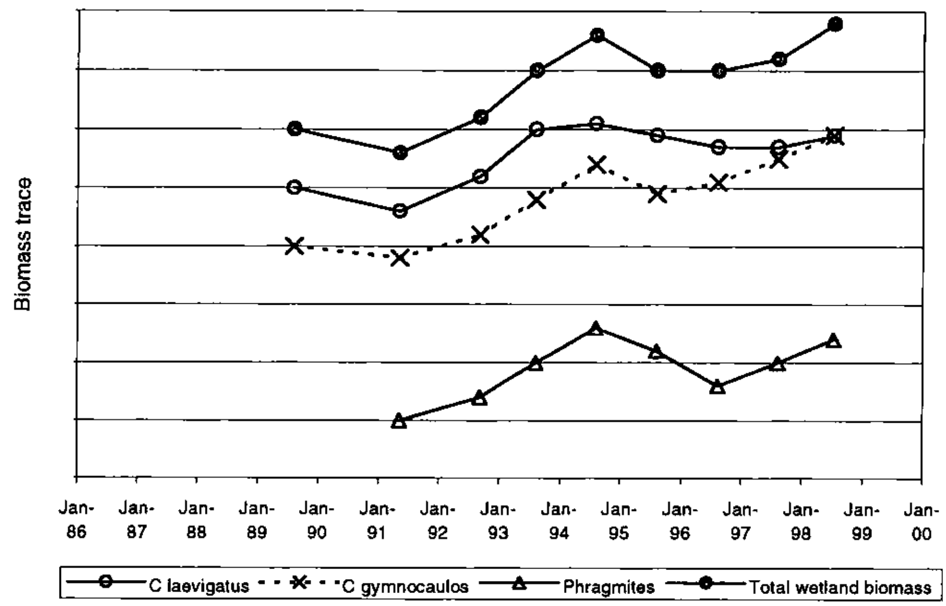
1991

1995

1992

1998

FIGURE I.4 The Fountain fenced tail Biomass trends
(combined PP1 & PP2 interpretation)



I.6 Interpretation

The vegetation of The Fountain has no intrinsic significance other than the fact of semi-aquatic plants being present.

The expansion of *Phragmites* on the vent has not been mirrored by growth on the lower tail, although there is some indication that it has brought about reduced flows into the tail. There is therefore no immediate need to manipulate the vent vegetation for maintenance of aquatic invertebrate populations.

The reasons for *Phragmites* failing to expand significantly in the tail (to date) are not known. It may well be a chance event. Water quality is not at issue, given the establishment of a small area of *Phragmites* down the tail at the fence. Nor is competition from other plant species, given the effective clearance of competition by stock in 1991. If its failure to expand is a function of chance events, then expansion to an equivalent of Outside Springs (Appendix J) and the establishment of a monoculture over the whole vent and tail remain possibilities. In such circumstances, local endemic invertebrate populations will be at risk.

I.7 Management issues and necessary actions

I.7.1 Vegetation management and fauna habitat

Manipulation of vegetation by grazing, in 1991, has been quite clearly demonstrated without apparent effect on the maintenance of hydrobiid populations (all species having been recorded as still present as part of the Lake Eyre South study). Intermittent grazing could therefore be considered to reduce the *Phragmites* cover on the vent and maintain the *Cyperus* wetland in the tail. However, the level of grazing needed to have any impact on the *Phragmites* cover in the vent carries dangers of heavy pugging elsewhere, including the tail.

Use of fire is an obvious possibility, particularly since the main fuel load of *Phragmites* is in the vent, not the tail. However, unless the *Phragmites* in the lower tail expands, or unless there are further flow reductions, there is no immediate need to undertake any manipulation. The Fountain is again a case of an isolated spring, with no nearby sources for re-colonisation by aquatic invertebrates. As elsewhere, there is only limited data, through the LESS, of precisely where the hydrobiid populations are in the spring. Errors of both commission and omission in vegetation management may have unrecoverable impacts on invertebrate populations. Trials for the sake of trials should therefore be performed elsewhere.

It follows however that monitoring must keep a watching brief both on *Phragmites* abundance in the tail and on flows. The latter can be monitored *de facto* by tracking the full extent of the tail, including the area outside the fenced enclosure.

I.7.2 Management recommendations

We recommend that:

- Monitoring of the spring be expanded to include a targeted tracking of the extent of the tail.
- Future manipulation of the *Phragmites* growth be considered, depending on results of trials elsewhere.
- Hydrobiid distributions within and outside the fenced area be monitored.

APPENDIX J
OUTSIDE

J. OUTSIDE

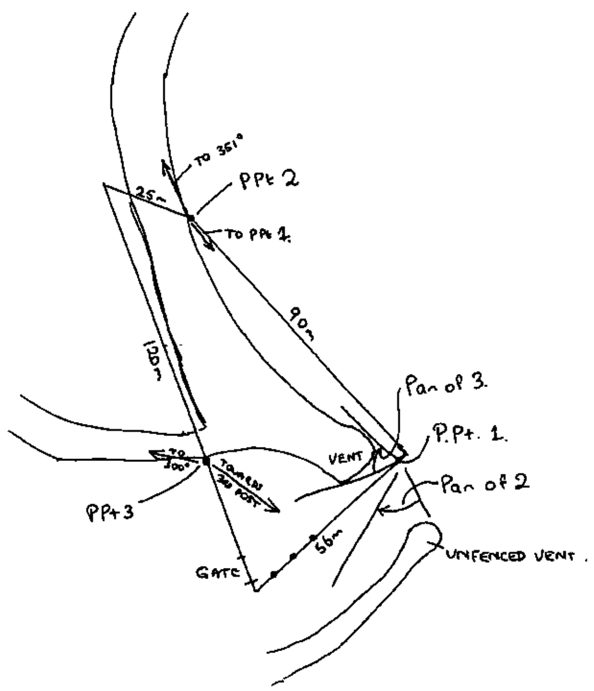
J.1 General

The Outside spring group has four widely spaced mounds, some with multiple vents. Fencing has been applied to one member of a pair of vents on a low silty mound (Figure J.1).

The two vents effectively had equivalent start points. The primary consequence of the fencing has been to shift the wetland vegetation from a high-richness, high-diversity, low biomass and low stand of mixed *Phragmites, Typha* and *Cyperus* species, to a low-richness, almost zero diversity, high biomass and tall stand of *Phragmites.* The *Phragmites* has expanded to totally occupy the fenced vent and all its tails within the fenced areas, with other semi-aquatic species either totally displaced or reduced to trace individuals on the extremities of the *Phragmites.*

There is no obvious impairment of flow: tails from the fenced vent are extensive beyond the fence, but there is no record and no current indication of whether their extent has reduced.

Figure J.1 Fencing and photopoints at Outside Springs



The plant species present are common semi-aquatic species, of no intrinsic value other than their presence in an otherwise arid environment. The invertebrate aquatic fauna however is of significance, with the hydrobiid fauna comprising the widespread *Fonscochlea zeidleri* and *F. aquatica,* the less widespread *Trochidrobia smithii,* and restricted species *Fonscochlea expandolabra* and *Trochidrobia minuta.* The last two species each are recorded for only six spring groups, of which four, including Outside, are small groups with few vents.

Ostracods, amphipods and isopods are present. Two fish species are present, the widespread Desert Goby and, unfortunately, the introduced Mosquito Fish. The last has been introduced to only one other spring group, also in the region.

J.2 Condition prior to fencing

There are no data from immediately prior to fencing. Brief notes in Symon (1985) and plant lists in SEA (1984) indicate a similar condition to the unfenced spring as seen in 1998.

J.3 Changes in incidence of plant species since fencing

Growth of *Phragmites* within the fenced vent and upper tails has resulted in the local changes listed in Table J.1.

Table J.1 Species eliminated or displaced from the fenced area at Outside

Species	*On vent and fenced tail*	*On unfenced portions of tails*
Cyperus laevigatus	Reduced to an isolated individual	Frequent to dominant
Typha domingensis	Eliminated	Present
Cyperus gymnocaulos	Eliminated	Frequent to dominant
Bolboschoenus caldwellii	Eliminated	Present

J.4 Expansion of wetland vegetation in fenced areas

J.4.1 Dominance and abundance alterations

The fenced area is entirely dominated by a stand of *Phragmites* to 5m tall, with a projective canopy cover well above the maximum field score of 100%. The *Phragmites* occupies both the original vent and upper tail areas. Its expansion has been halted at the fence by grazing pressure.

The immediately adjoining unfenced vent, in contrast, has a mixed stand of *Phragmites* and *Typha* to 1.2m, with combined cover in 1998 of some 40-50%, with abundant *Cyperus laevigatus* and *C. gymnocaulos.*

Unfenced tails vary in composition, with plant heights generally below 1m, total plant cover in the range 30-60%, and a high-diversity mixture of species. *C. laevigatus, C. gymnocaulos, Typha,* and *Phragmites* are all abundant.

The expansion of *Phragmites* in the fenced area has been such that no single set of photographs allows a full comparison of changes. Figures J.2 and J.3 illustrate part of the sequence documented in Figure J.4

In 1991, after fencing, the fenced area had already developed a strongly growing *Phragmites* cover, with some *Typha* also present. *Phragmites* biomass peaked in 1994/1995 and has since remained stable. *Typha* was eliminated by mid 1994.

The unfenced spring area, however, has simply oscillated under grazing. *Phragmites* and *Cyperus laevigatus* inversely vary, *Phragmites* reducing under increased stocking pressure (Figure J.3, J.4)

FIGURE J.2
OUTSIDE SPRING FENCED VENT

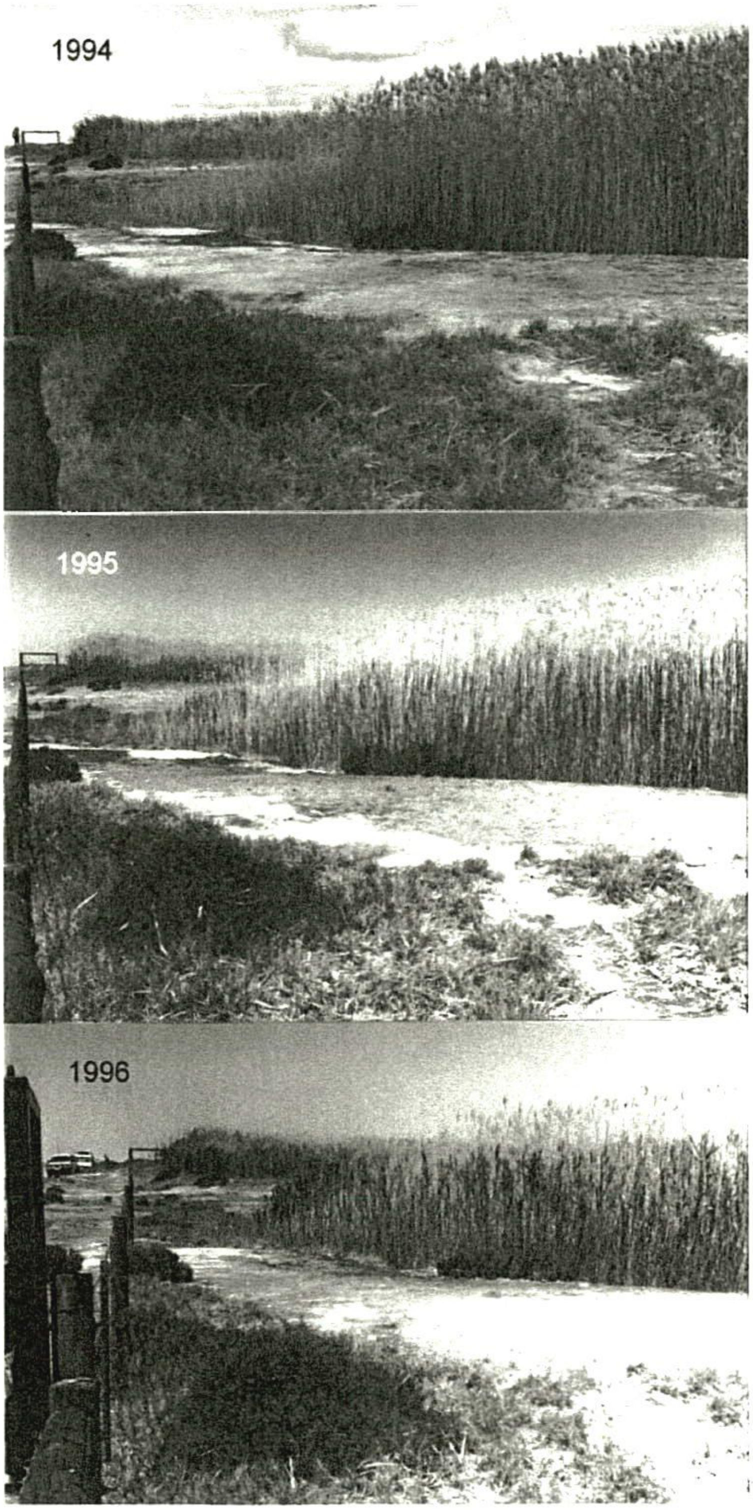
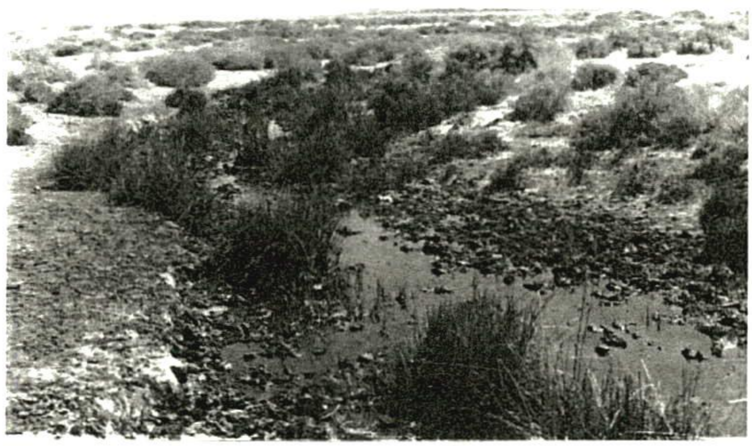


FIGURE J.3
OUTSIDE SPRING UNFENCED VENT

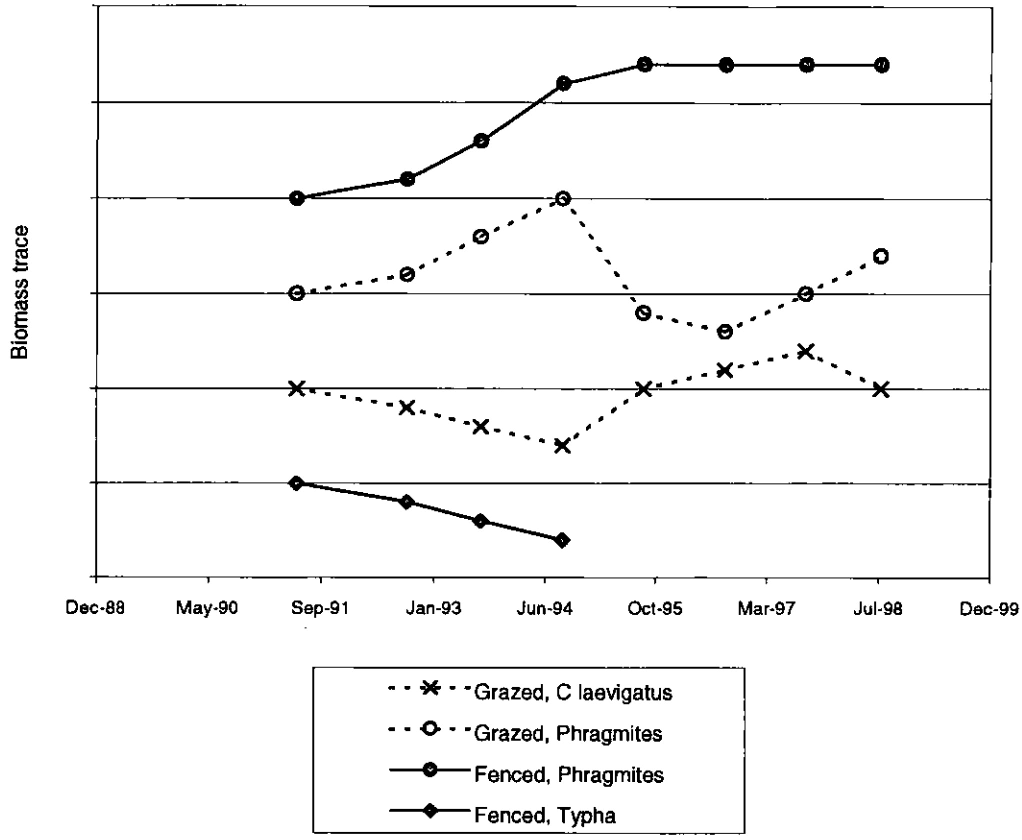
1994

1995



1996

FIGURE J.4 Outside Springs vent areas biomass trends
(Fenced area shown as solid line)



J.4.2 Wetness changes

There are no obvious indications of a reduction in flow as a consequence of the increase in *Phragmites*. Tails fed by the fenced vent remain extensive, but there are no comparative data on their pre-fencing extent or flows. It is clear that the *Phragmites* is held from further expansion by grazing, and even the present extensive stands may not be sufficient to affect visible flows significantly.

J.5 Cover and plant diversity in context

The fenced area at Outside has a wetland cover higher than all other fenced wetlands except Big Cadna-owie. Wetland cover on the unfenced areas is at median levels for the sample (Figure A.2)

Plant species richness for the local fenced and unfenced areas combined is mid-range compared with other groups, fenced and unfenced (Figure A.3). The differential in plant species richness and diversity is clearly demonstrated in Figures A.6 and A.7.

J.6 Interpretation

On appearances, the fencing has been a failure if measured in strict terms of maintaining hydrobiid habitat, maintaining wetland species richness and protecting or increasing plant diversity. However, it can be reasonably argued that the general biodiversity in the group has been enhanced, whether or not it was intended, by the appearance of a low richness, low cover-diversity, high biomass stable unit in proximity to a high richness, high cover-diversity, low biomass fluctuating system.

The point is made that pluralistic approaches to management, within reason, can increase the diversity of outcomes, and that no single outcome is necessarily the only desirable one.

Outside Springs conform closely to the model of responses proposed from the Lake Eyre South springs.

J.7 Management issues and necessary actions

J.7.1 Vegetation management

Maintenance of flow from the fenced vent would normally be of some concern, given the presence in the group of two hydrobiids of very restricted distribution. Manipulation of vegetation might seem appropriate both to ensure flows are maintained and to keep some relatively open water areas for hydrobiid habitat. However, given the close proximity of the unfenced vent and extensive tails, there is no pressing reason for doing so simply to maintain those habitats, given the intermittent nature of controls imposed by stocking.

However, the fenced vent does allow the possibility of a major trial of the effects of burning as a control measure specifically for *Phragmites*. Possibilities of accidentally destroying immediately local hydrobiid populations are mitigated by the presence of the immediately adjoining unfenced spring, from which natural colonisation or intentional assisted invasion could proceed. Further, the immediately adjoining spring is under no threat of accidental burning, given its low cover.

J.7.2 Other issues

It would be desirable to eliminate the Mosquito Fish from Outside spring group, to minimise the possibility of it being transferred more widely through the spring system. Approaches to its eradication need to be investigated, with particular emphasis on possible side-effects of eradication methods on the aquatic invertebrates.

J.7.3 Management recommendations

We recommend that:

- A controlled burning experiment be run on the *Phragmites* within the fenced area at Outside Spring, using the unfenced spring as a control
    - A check be made of any hydrobiids in the area to be burnt, and downstream, to ensure that the species are also present in the control area.
    - The trial to be appropriately designed, with pre-burning measurement including water flow and downstream chemistry, direct recording of the burning operation, and rigorous monitoring of the outcome.
- The possibilities of eradicating Mosquito Fish from the group be examined.

APPENDIX K

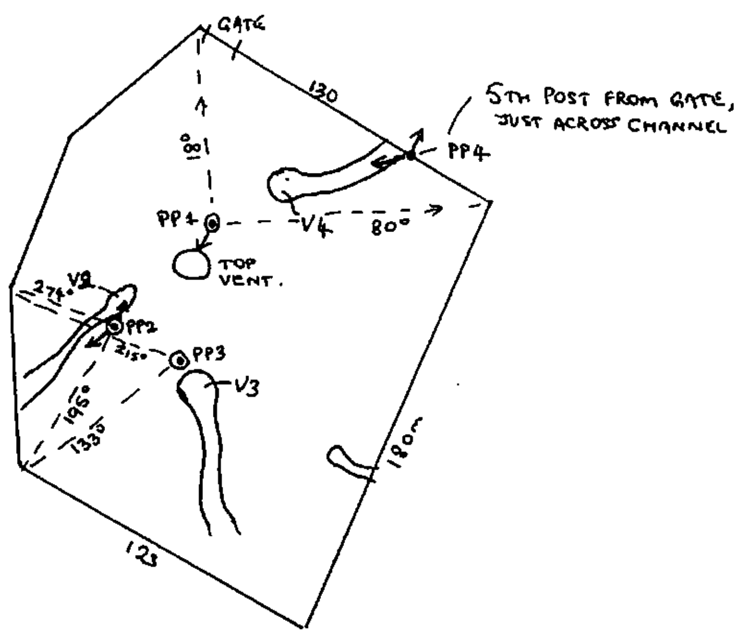
TWELVE MILE

K. TWELVE MILE

K.1 General

Twelve Mile is a collection of some eight vents, five of which are present on a single, silty gypseous mound. Fencing encloses 2.6 ha around the base of the mound (Figure K.1). Some tails extend through the fence and are grazed. The group was fenced in the past, in common with other springs in the 19th and early 20th C.

Figure K.1 Fencing, vent areas and photopoints, Twelve Mile



Vent 1 ("top vent") has ceased to flow since fencing. Two new fissure vents (unlabelled on Figure K.1) have opened since fencing.

There is a mixture of dominant plants on vents: *Phragmites* is the most common dominant, on vents 2, 4 and both the new fissures. *Typha* dominates vents 1 and 3. *Juncus krausii* dominates a damp area indicating a former flowing vent near the top vent. Vegetation in tails is variable.

With the release from grazing, there has been a major accumulation of dryland plant biomass and the spring-associated grass *Sporobolus virginicus.*

Twelve Mile is of significance for its possession, together with Big Perry, Outside and the Fountain, of the very restricted hydrobiid species *Fonscochlea expandolabra* and *Trochidrobia minuta.* The widespread *Fonscochlea zeidleri* and *F. aquatica* and the less widespread *Trochidrobia smithii* are also present.

K.2 Condition prior to fencing

Symon (1985) reported Twelve Mile as a large low mound with "numerous seeps and active to small flows of water". He mentioned evidence of "peats" and past burning. His description generally together with the early photographs in the DEHAA monitoring series, indicate less free water evident now than prior to fencing. Descriptions in SEA (1984) are not adequate to form any judgement.

K.3 Changes in incidence of plant species since fencing

Table K.1 lists species present well before the group was fenced. There are no records of changes at the time of fencing. Points of particular note are:

- *Typha* appears to be a post-fencing arrival in the group
- The marsh species **Cotula coronopifolia, Samolus repens* and **Polypogon monspeliensis* have disappeared, suggesting some contraction of tails or at least tail margins.
- *Enchylaena tomentosa* has established given the protection from grazing.

Table K.1 Plant species records pre- and post- fencing, Twelve Mile

Species	*Symon (1985), SEA (1984)*	*August 1998 inspection*
Acacia victoriae	X	X
Cotula coronopifolia	**X**	**Not present, implies reduced open water**
Cyperus gymnocaulos	X	X
Cyperus laevigatus	X	X
Enchylaena tomentosa	**Not present**	**X**
Frankenia sp	X	X
Halosarcia halocnemoides	X	X
Halosarcia indica	X	X
Juncus krausii	X	X
Nitraria billardieri	X	X
Phragmites australis	X	X
Polypogon monspeliensis	**X**	**Not present, implies reduced wetness at ends of tails**
Samolus repens	**X**	**Not present, implies reduced wetness at ends of tails**
Spergularia rubra	X	
Sporobolus virginicus	X	X
Typha domingensis	**Not present**	**Major vent species**

K.4 Expansion of wetland vegetation in fenced areas

Not all photos are available at the time of fencing in 1991. Incipient changes were rapid.

The examples provided here are from DEHA PP1, of the now extinct top vent, and of PP3, a tail on which vegetation is continuing to expand. Figure K.2 is a photo-series showing what is believed to be an initial rapid expansion of *Typha* in the top vent to 1992 (initial photo), followed by vent plugging and a gradual diminution in *Typha* to 1998. The biomass trend plot (Figure K.4) is equivalent.

Photographs in Figure K.2 commenced at the time of fencing, with obvious heavy grazing and light pugging. *Cyperus laevigatus* in this tail diminished, and vanished from the photograph by 1994. Both *C. gymnocaulos* and *Phragmites* expanded greatly to 1996. Since 1996, the photos can be interpreted as either showing biomass at an irregular plateau, or continuing to increase at a reduced rate.

K.5 Cover and plant diversity in context

In relation to other fenced spring groups, Twelve Mile has a mid-range wetland cover, but higher than most unfenced spring groups. Wetland plant species richness and cover diversity however are both low compared to other fenced and unfenced springs.

K.6 Interpretation

The one example of clear evidence of reduced or blocked flows is the decline and extinction of vent 1 under *Typha* growth. Although growth has been major in other vents, tails are still extensive. It would appear that new fissure springs have developed due to local plugging of previous vents by *Phragmites* and *Typha*. Records are not adequate for certainty.

The appearance of new vents in the same mound is expected, and as regards the vegetation, is considered a major mechanism in maintaining plant diversity on springs. It is not known, however, whether the aquatic invertebrates can or have colonised these new vents, nor the mechanism by which they might do so.

Vegetation on tails is continuing to increase, with increased height and cover as dominance shifts from *Cyperus laevigatus* to *C. gymnocaulos*. *Phragmites* is extending downslope and can be expected to continue to where tails cross the boundary fence. Open water areas have generally reduced.

FIGURE K.2
TWELVE MILE VENT CLOSURE

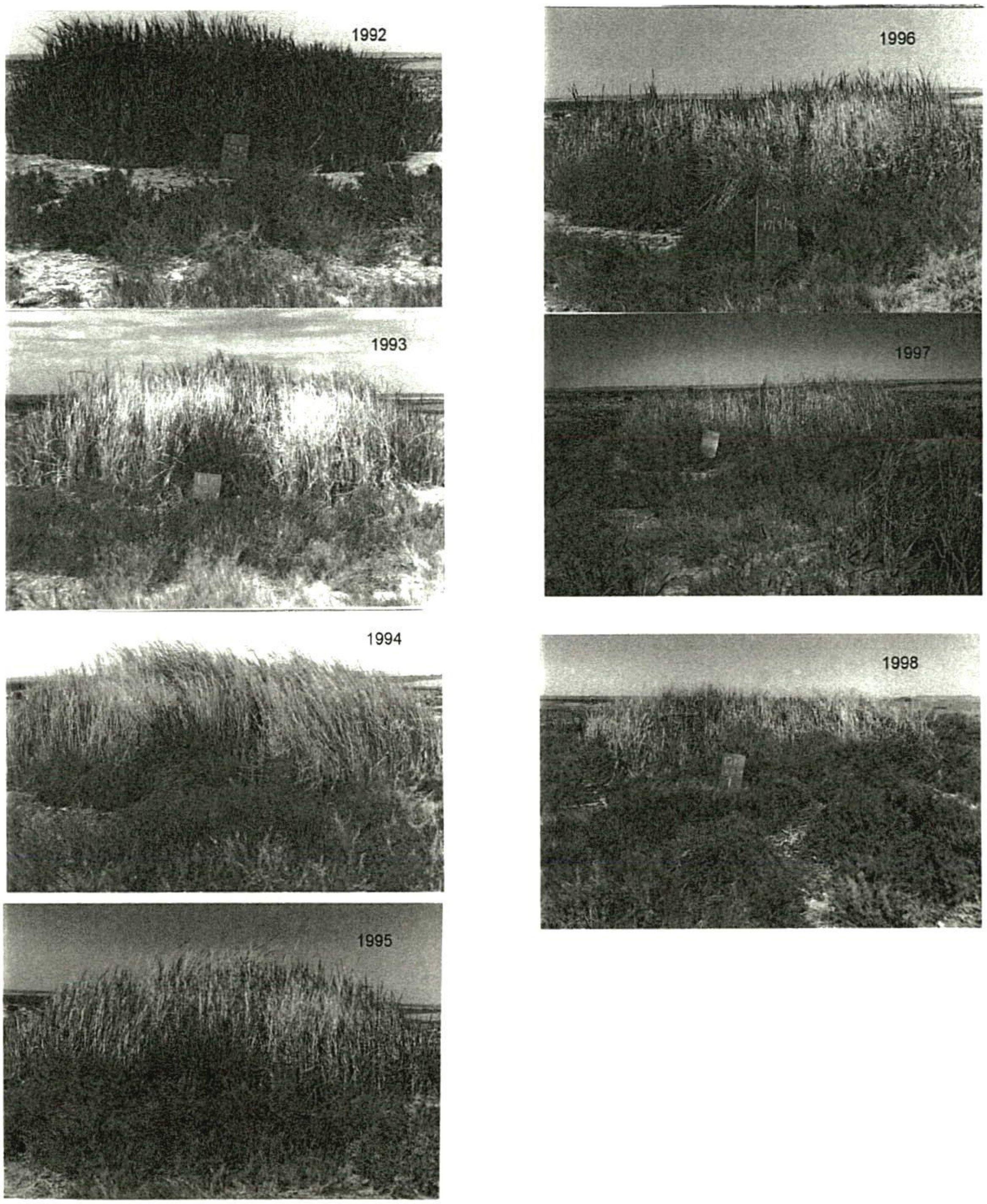


FIGURE K.3
TWELVE MILE TAIL 1991-1998

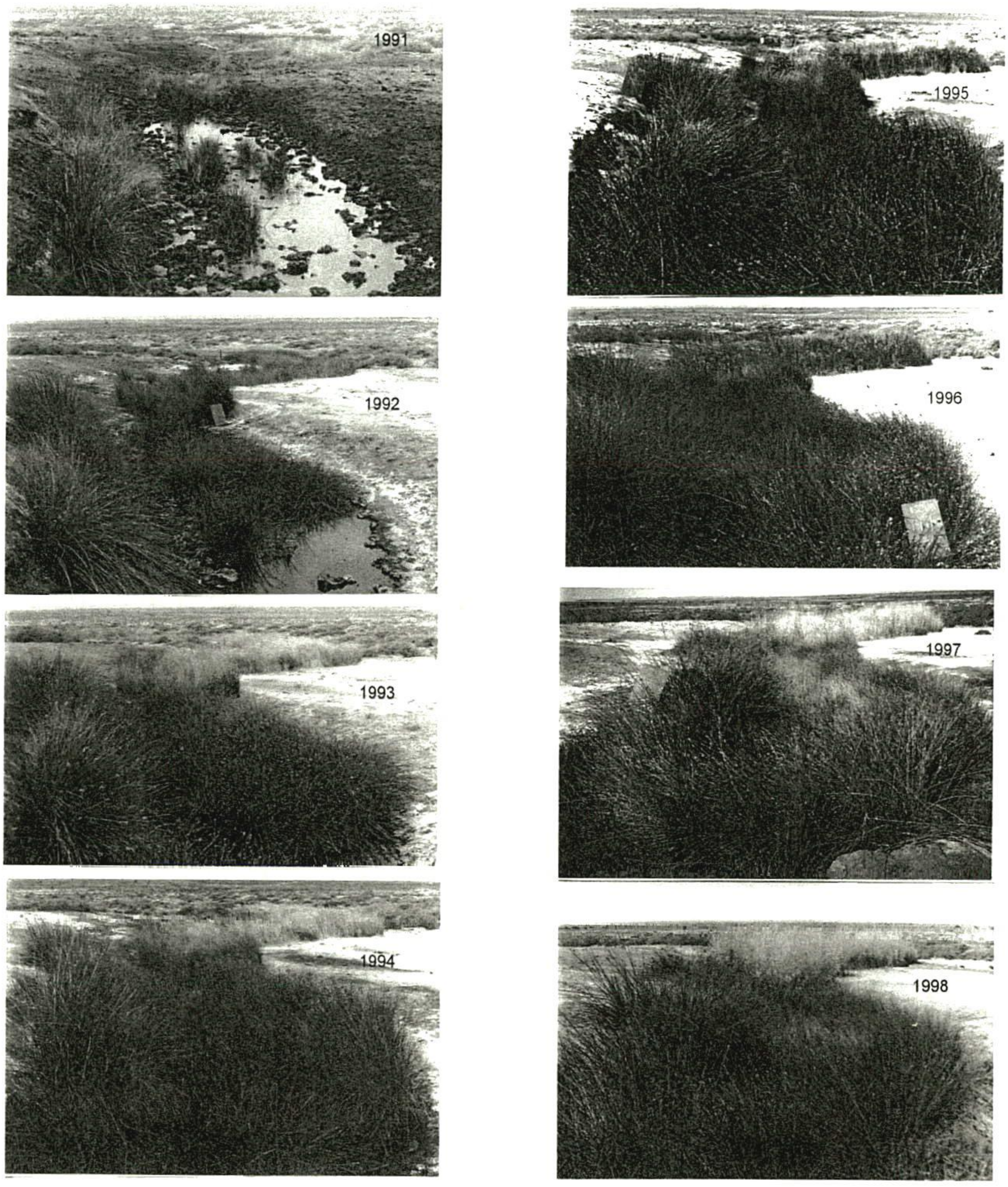


FIGURE K.4 Twelve Mile PP1 (Isolated vent)
Biomass Trends
(No photo for June 1991: assumed low cover of all species)

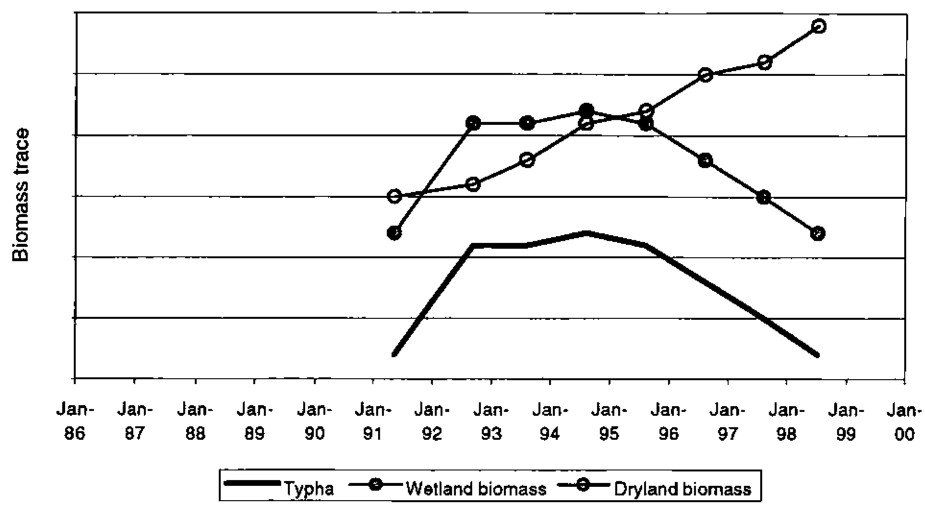
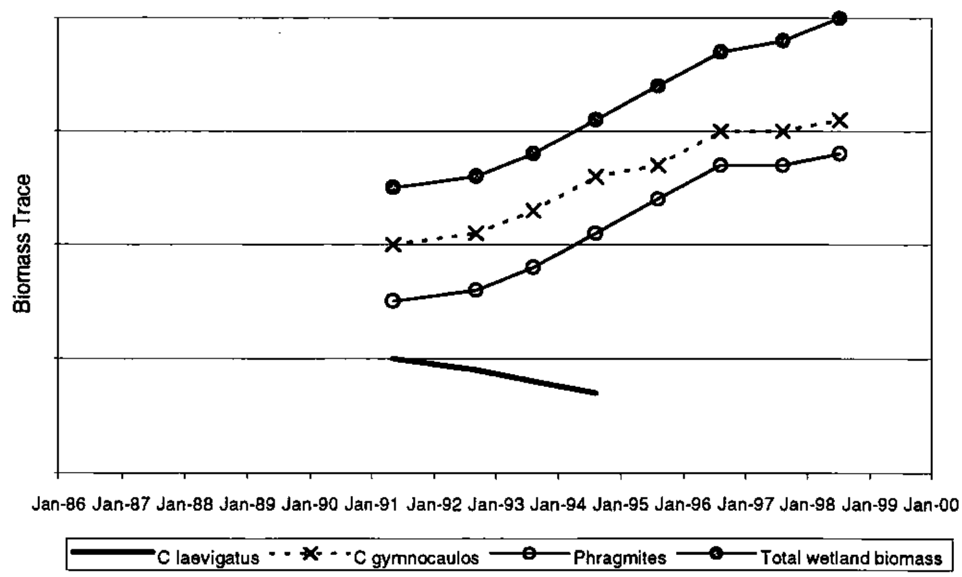


FIGURE K.5 Twelve Mile PP3 Fenced Tail
Biomass Trend



K.7 Management issues and necessary actions

K.7.1 Vegetation management

Until it is known whether the aquatic invertebrates, primarily the hydrobiids, can move rapidly to colonise new vents, there is a case for manipulating vegetation on the older, major vents, to ensure flows are maintained. Further, maintenance of some open-water areas on the mound slope may be necessary to maintain hydrobiid populations. Again, approaches are limited by lack of data on hydrobiid dynamics and specific habitat preferences.

Twelve Mile does however provide replicate areas on the fenced mound for experimentation. In particular, one of the older *Phragmites* dominated vents and tails could be manipulated, using the other *Phragmites* vents and tails as controls, without risk to the aquatic invertebrates on the mound as a whole. A sequential combination of operations is suggested: burning of the dense *Phragmites*, and a later cutting of *C. gymnocaulos* in the lower tail. Such a trial could be undertaken in conjunction with the recommended trial of burning *Phragmites* at The Fountain, thus providing both grazed and ungrazed controls.

The isolated top vent allows a trial of burning *Typha* as a means for increasing surface water flow. The vent is isolated and there is no free water now present, hence no risk is posed to aquatic invertebrates. The trial could be undertaken as an adjunct to the recommended trials at Tarlton, or as a replication of them.

K.7.2 Other issues

Symon (1985) referred to "signs of deep peats having been burnt over the now rocky mound". We query whether the peats if present were in fact deep. However, the possibility of some peat deposits remaining is a further reason for not extending the proposed burning trials to all vents.

K.7.3 Management recommendations

We recommend that:

- The use of fire as a management tool in *Phragmites* be tested in one of the *Phragmites*-dominated springs and tails at Twelve Mile, with other *Phragmites* vents and tails used as local controls.
- The *Phragmites* trial be designed and undertaken in conjunction with the proposed trial at The Fountain.
- The use of fire as a management tool in *Typha* be tested in the isolated and now dry "top vent".
- The *Typha* trial be run as an adjunct to the trials proposed for Tarlton.
- Both trials be appropriately designed, with pre-burning measurement, direct recording of the burning operation, and rigorous monitoring of the outcome.

APPENDIX L

COWARD

L. COWARD

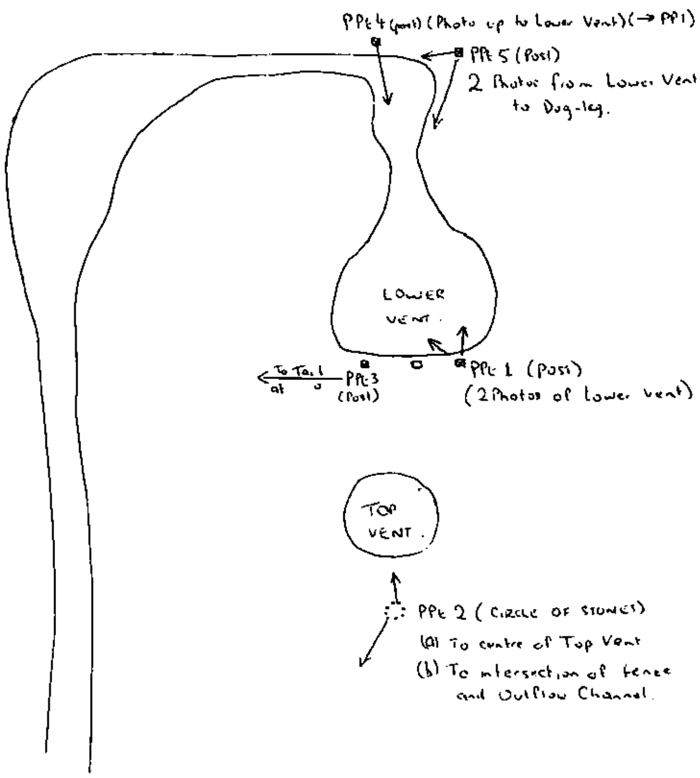
L.1 General

Coward Spring is a single large travertine mound with two major vents, one with a tail extending onto floodplain, and some very small seepages. It is the most recently fenced, in 1996. The spring vent vegetation is in the process of change from low diversity-low biomass *Cyperus laevigatus*-dominated vents to low diversity-high biomass *Phragmites*-dominated vents. The single tail is increasing its diversity, although there is no change in plant species present.

In view of problems of *Phragmites* dominance in earlier, small fenced areas, fencing at Coward is distant from the vent, and includes the mound and all of its tail area.

The vents and tail share the same invertebrate fauna with other springs in the Coward group (see Appendix B, Blanche Cup), with ostracods, amphipods, isopods, three species of the hydrobiid *Fonscochlea* and one of *Trochidrobia* present.

Figure L.0 Layout of Coward Springs within the fenced area



L.2 Changes in incidence of plant species since 1984

Plant species on this spring in 1978 were described by Symon (1985). No change in incidence was noted in 1998.

Condition as described by Symon for 1978 and by SEA (1984) effectively match, of vents rather pugged by cattle and a tail of low biomass.

L.3 Expansion of wetland vegetation in fenced areas

L.3.1 Dominance and wetness changes

Changes are best illustrated by the two available photo sets.

The secondary vent was grazed and pugged, with freewater visible, in 1996 (Figure L.2), dominated by *C. laevigatus* with low *Phragmites* and a clump of *Juncus krausii.* By 1998, the vent was dominated by 2m high *Phragmites,* some *C. laevigatus* was still evident but the *Juncus* was totally obscured, No free water was evident. This vent can be expected to become a monoculture of *Phragmites* within two to three years.

The primary vent in 1996 was in similar condition, but with very little *Phragmites* present (Figure L.3). By 1998, the vent was almost entirely dominated by *Phragmites.*

The tail on the mound slope has remained dominated by *Cyperus laevigatus* but biomass has increased (Figure L.3)

In 1996, shortly after fencing, lower tail areas were dominated by *Cyperus laevigatus* with some *Schoenoplectus litoralis* and sparse *Phragmites* (background, Figure L.1). Major changes have since occurred. These can be demonstrated in general from photographs, but direct sampling would provide clearer information. From the 1998 inspection data, what appears to have happened is that:

- *C. laevigatus* still contributes the main part of the cover of the tail
- *Phragmites* has become well established in the tail, from which it was previously absent, at the foot of the mound, and is extending further downstream
- *Bolboschoenus caldwellii* has been displaced by *Phragmites* but itself has established further down the tail.

For the tail as a whole, cover-diversity is high, but arises from the previous three species dominating in different areas of the tail. This will change as the latter two species extend their distribution.

L.4 Cover and plant diversity in context

In relation to other fenced springs, the area fenced at Coward is of mid-range species richness, cover and cover-diversity (Figures A.2, A.3, A.4). This may well change if dominance shifts continue within the tail.

1996

1998

FIGURE L.1
COWARD MOUND

1996

FIGURE L.2
COWARD TOP VENT
(no tail on vent)

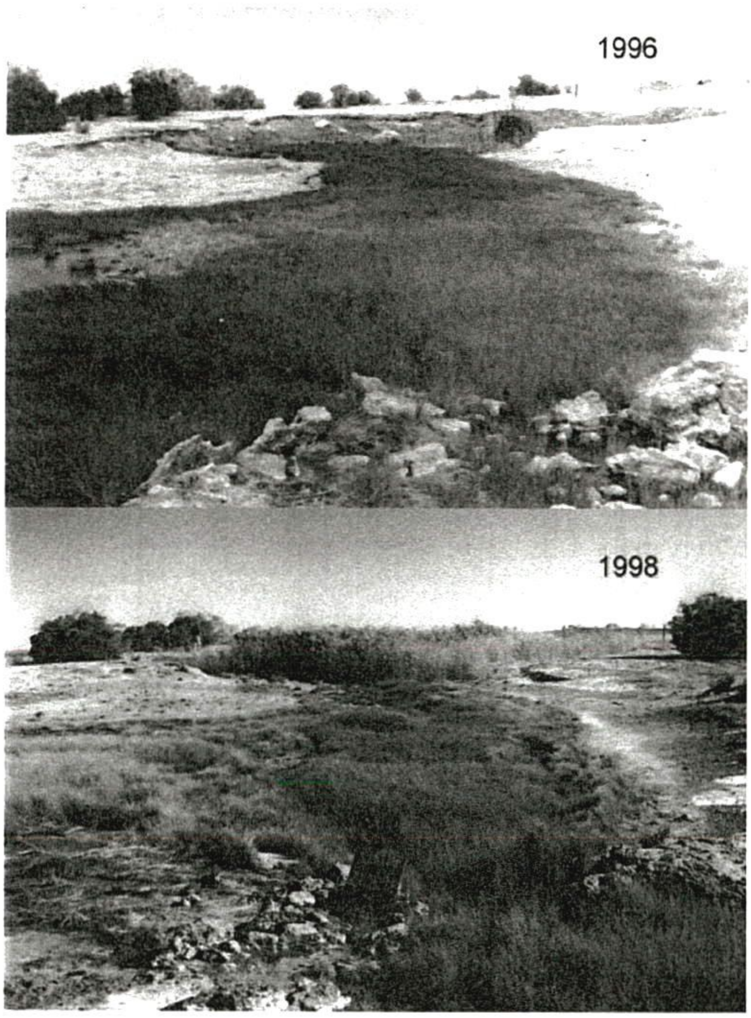


**FIGURE L.3
COWARD MOUND
MAIN VENT
& UPPER
TAIL**

L.5 Interpretation

Coward is following the pattern demonstrated by the majority of springs around Hermit Hill. *Phragmites* on vent areas can be expected to increase to the point of monoculture. For the top vent, no more than damp conditions can be expected, as transpiration rates and vent blocking come into play. For the main vent and tail, the extent to which *Phragmites* comes to dominate will depend on the absolute flow rate. Flow may be high enough to permit the survival of other species, in quantity, beyond the (unknown) limits to *Phragmites* distribution. It is more likely, however, that:

- available free water will reduce,
- *Phragmites* will dominate most of the tail,
- Other plant species will remain present but only as minor components

Such an outcome is likely to have adverse effects on at least some of the endemic invertebrate fauna.

L.6 Management issues and necessary actions

L.6.1 Vegetation management

At present, Coward is an example of a spring at its maximum diversity, during the changeover from a stock-induced balance to a vegetation-induced balance. This is a state which we consider it desirable to reproduce in other springs, to maintain biodiversity.

Accordingly, there is no immediate need to manipulate the vegetation now. However, there is likely to be such a need in the near future. Evidence from Hermit Hill indicates a span of no more than six or so years for *Phragmites* dominance to reach a steady-state. Hence, decisions whether or not to manipulate the vegetation will be required within the next three years.

In particular, given the isolation of Coward Springs and the (relative) richness of its endemic invertebrate populations, close monitoring of available fauna habitat should be undertaken in conjunction with the watch on vegetation. If there is significant reduction of free-water as a consequence of the dominance shifts, then decisions to manipulate the vegetation will be required in a shorter term.

L.6.2 Other issues

Given that the top vent is already dominated by *Phragmites* and already lacks free water, it provides an opportunity for a trial of burning *Phragmites* with no risk to aquatic fauna (already lost, if originally present) and with ease of access for operation and monitoring.

L.6.3 Management recommendations

We recommend that:

- The level of vegetation monitoring on Coward Spring be increased, in particular to include estimates of individual species' abundance above that provided by the photopoints.
- The extent of free water be closely monitored, with regard to aquatic invertebrate habitat.
- An immediate trial of burning *Phragmites* in the top vent be undertaken, with pre- and post-burning monitoring of vegetation, wetness, and any re-invasion by aquatic fauna.

- In the longer term, and depending on the outcome of the previous three recommendations, the spring vegetation be manipulated to maintain at least a diverse set of habitats and vegetation in the tail.

APPENDIX M

EXAMPLES OF ENDEMIC INVERTEBRATE DISTRIBUTIONS IN SPRING GROUPS

M. EXAMPLES OF ENDEMIC INVERTEBRATE DISTRIBUTIONS IN SPRING GROUPS

Only groups with endemic hydrobiids are shown.

Data are from Kinhill Engineers (1997). Hydrobiid data derived from Ponder et al. (1989, 1995)

Spring Complex and Group	*Hydrobiid snails*										*Others*		
	Fonscochlea zeidleri	*Fonscochlea aquatica*	*Fonscochlea accepta*	*Fonscochlea variabilis*	*Fonscochlea billakalina*	*Fonscochlea expandolabra*	*Trochidrobia punicea*	*Trochidrobia smithii*	*Trochidrobia minuta*	*Trochidrobia inflata*	Amphipods	Isopods	Ostracods
BERESFORD HILL													
Beresford group	x	x		x				x			x	x	x
Warburton group	x	x		x				x			x	x	x
BILLA KALINA													
Billa Kalina	x	x			x			x			x	x	x
Fenced Spring	x	x		x				x					
Welcome Spring	s				s								
COWARD													
Blanche (whole group)	x	x		x			x				x	x	x
Coward	x	x		x			x				x	x	x
Coward railway bore	x			x									
Elizabeth	x	x		x			x				x	x	x
Horse East, Horse West	x	x		x			x				x	x	x
Jersey	x	x		x			x				x	x	x
Julie	x	x		x			x				x	x	x
Kewson Hill	x	x		x			x				x	x	x
Mt Hamilton	x	x		x			x				x	x	x
Strangways	x	x		x			x						x
FRANCIS SWAMP													
Francis swamp group	x	x			x			x			x	x	x
HERMIT HILL													
Bopeechee	x		x	x			x				x	x	x
Dead Boy			x				x				x	x	x
Hermit	x		x				x				x	x	x
Old Finniss	x		x				x				x	x	x
Old Woman	x		x	x			x				x	x	x
Sulphuric			x				x				x	x	x
Venables	s		s	s			s						
West Finniss	x		x	s			x				x	x	x
LAKE EYRE													
Centre Island	s												x
Emerald			x								x	x	x

Spring Complex and Group	*Hydrobiid snails*										*Others*		
	Fonscochlea zeidleri	*Fonscochlea aquatica*	*Fonscochlea accepta*	*Fonscochlea variabilis*	*Fonscochlea billakalina*	*Fonscochlea expandolabra*	*Trochidrobia punicea*	*Trochidrobia smithii*	*Trochidrobia minuta*	*Trochidrobia inflata*	Amphipods	Isopods	Ostracods
MOUNT DUTTON													
Big Cadna-Owie	x												
NEALES RIVER/MT MARGARET													
Big Perry	x	x				x		x	x		x	x	x
Brinkley	x	x						x			x	x	x
Hawker	x	x				x		x			x	x	x
Outside	x	x				x		x	x		x	x	x
Spring Hill	s												x
Fountain	x	x				x		x	x				x
Twelve Mile	x	x				x		x	x		x	x	x
PEAKE CREEK													
Freeling (Repeater Station)	x	x				x			x	x	x	x	x
Freeling (north)									x		x	x	
STRANGWAYS (REPEATER STATION)													
Strangways	x	x				x			x		x	x	x
WANGIANNA													
Davenport	x		x	x			x				x	x	x
Welcome	x		x	x			x				x	x	x