CSIRO

Water Regime of Wetland & Floodplain Plants in the Murray-Darling Basin

A Source Book of Ecological Knowledge

Jane Roberts and Frances Marston

CSIRO Land and Water, Canberra
Technical Report 30/00, October 2000

CSIRO LAND and WATER

Water Regime of Wetland & Floodplain Plants in the Murray-Darling Basin

A Source Book of Ecological Knowledge

Jane Roberts & Frances Marston

CSIRO Land and Water, Canberra
Technical Report 30/00, October 2000

Published by:

CSIRO Land and Water
GPO Box 1666
Canberra ACT 2601

Copies of this report may be obtained by contacting:

The Communications Officer, CSIRO Land and Water, GPO Box 1666, Canberra ACT 2601

Phone: 02 6246 5700 (switchboard)

Email: communication@clw.csiro.au

Please cite this publication as:

Roberts, J. and Marston, F. (2000). Water regime of wetland and floodplain plants in the Murray-Darling Basin: A source book of ecological knowledge. CSIRO Land and Water. Technical Report 30/00. October 2000. Canberra.

ISBN 0 643 06084 7

Cover Photograph:

Mirrool Creek floodway, west of Barrenbox Swamp, NSW, February 1992.

Table of Contents

Introduction

Purpose

This is a summary of water regime information for native plants of lowland riverine systems within the Murray-Darling Basin.

This information is needed when planning river flows or when making water allocations, particularly in relation to individual floodplains, single billabongs and large floodplain wetland complexes. Finding this information can be difficult: either it does not exist, or it is scattered.

This summary brings together this sparse and dispersed information into a single document, as a resource for persons and organisations involved in ecological aspects of river flow and wetland management.

Scope

The plant communities targetted here are those typical of or dominating large areas of wetlands and floodplains associated with the lowland riverine systems in the Murray-Darling Basin. These are mainly freshwater habitats, so the focus is on freshwater species. Saltmarsh plants, salt-tolerant macrophytes and halophytes are not covered.

Information

Original information and data have been used as far as possible. Actual sources used include: papers from scientific journals; reports from a number of sources but mostly prepared by government agencies and departments, research institutions, and consultants; unpublished research, such as student theses; and personal observations, but to a limited extent.

Information on species water regime is, in most cases, sparse because so few species have been studied.

The types of information available are varied and of variable quality. Single species experiments where one aspect of water regime is manipulated are most useful as these provide plant responses to a range of conditions; these can also define the extreme or intolerable conditions. Other sources of information are modelling studies, field observations, and certain types of mapping. Floodplain inundation mapping is very useful in describing average flood frequency and its variability for different vegetation types, but it is less effective at finer scale information such as depth tolerance, seasonal requirements, desiccation tolerance, and germination and establishment conditions. Some of these answers can only come from experimental studies.

Experimental or modelled studies give more detail than field observations: a limitation of field observations is there may be site-specific factors or processes other than water regime (eg competition) that are limiting the species distribution.

Format

Detailed water regime information is presented for species most likely to dominate lowland wetland or floodplain systems of the Murray-Darling Basin. These species are presented, grouped by growth-form and described by vegetation type: tree, shrub, grasses, sedges and rushes, submerged macrophytes, and herbs and forbs.

The water regime required to ensure growth, flowering and survival of an established mature perennial plant is usually different from the water regime needed to ensure the establishment of a new generation. Thus these two phases are described separately as *Maintenance* and *Regeneration*.

The important components of water regime for plants of rivers, wetlands and floodplains are: frequency of flooding; timing (ie season); duration; and depth. Also important for plants in wet-dry habitats (most lowland riverine systems in the Murray-Darling Basin) are the period between floods, ie drought; and variability of either wet or dry conditions.

Feedback

Feedback is an important part of providing this information summary, and comments are welcomed. Please advise of errors and misinterpretations, of gaps and of additional sources:

jane.roberts@cbr.clw.csiro.au
Jane Roberts
CSIRO Land and Water
GPO Box 1666, Canberra, ACT 2601

frances.marston@cbr.clw.csiro.au
Frances Marston,
CSIRO Land and Water,
GPO Box 1666, Canberra ACT 2601

Related Reports

This is the last of three reports prepared as background documents for the 'Ecology Flows Study'. Some of this material is incorporated into a handbook 'Rivers – Ecological systems of the Murray-Darling Basin' (editor, W.J.Young 2000); and the handbook is supporting material for EFDSS (Environmental Flows Decision Support System), prepared for the Murray-Darling Basin Commission by CSIRO Land and Water.

The first two reports were:

Relationships between waterbird ecology and river flows in the Murray-Darling Basin. Anthony Scott. CSIRO Land and Water. Technical Report 5/97. June 1997. Canberra.

Impacts of water management in the Murray-Darling Basin on the platypus (*Ornithorhynchus anatinus*) and the water rat (*Hydromys chrysogaster*). Anthony Scott and Tom Grant. CSIRO Land and Water Technical Report 23/97. November 1997. Canberra.

This source book also supports the advisory manual published by LWRRDC:

Estimating the water requirements of plants of floodplain wetlands: a guide. Jane Roberts, Bill Young and Frances Marston. LWRRDC Occasional Paper No 04/00. Land and Water Resources Research and Development Corporation, Canberra. September 2000.

Acknowledgements

Many thanks to the following scientists whose comments and inputs improved this report:

Margaret Brock, Department of Land and Water Conservation, Armidale, NSW

Michelle Casanova, Westmere, Victoria

Judy Frankenberg, Murray-Darling Freshwater Research Centre, Albury, NSW

Surrey Jacobs, Royal Botanic Gardens, Sydney, NSW

John Porter, National Parks and Wildlife Service, Hurstville, NSW

Keith Ward, Department of Natural Resources and Environment, Benalla, Victoria.

TREES
Forests & Woodlands

Trees are large woody plants, usually with one main stem at ground level. The accepted sense of 'forest' in Australian plant ecology is an area of mature trees with at least 30% foliage projective cover (eg Specht 1994). If projective foliage cover is less than 30%, then the vegetation is a woodland. This definition of a forest is not intended to be applied to dense re-growth patches, as these have not yet reached their stable configuration; normally, before these reach maturity, they will self-thin.

Forests are distinct from woodlands in having higher tree density than woodlands, and straighter boles with less branching: woodland trees tend to have an open, spreading 'savannah' form.

Distribution

In the Murray-Darling Basin, closed floodplain forests (ie with projective canopy >70%) are restricted to relatively-wetter floodplains, so occur mainly on floodplains of large rivers in southern parts of the Basin, typically the Murray, Murrumbidgee and parts of the Goulburn Rivers. Open floodplain forests (canopy 30-70%) are more widely distributed, occurring as pockets or as a gallery fringe beside main river channels. As most of the lowland floodplains of the Murray-Darling Basin are relatively dry, and flooding is infrequent, woodland is the more usual vegetation type particularly in the western part of the Basin.

Eucalyptus species

Tree species richness is low in riparian and floodplain forests and woodlands of the Murray-Darling Basin, when compared with tropical or overseas floodplain forests and woodlands. *Eucalyptus* are the dominant riparian species, virtually throughout the Basin. Unlike many eucalypt woodlands, usually there is only one species present.

Stands dominated by different eucalypt species may occur on the same floodplain, but are usually at different elevations or on different soil types or fluvial forms. This sorting is usually due to differences in physiology and/or ecology. Comparative ecophysiological studies of River Red Gum and Black Box show that these differ in their tolerance of flooding, and of dry conditions.

Species differences are particularly noticeable in seedlings. The more flood tolerant species have morphological adaptations such as adventitious roots and aerenchymatous tissue (Heinrich 1990, McEvoy 1992). It is also evident in established trees: mature River Red Gum has high transpiration rates, whereas transpiration rates in Black Box are very low. The distribution of Coolibah on floodplains suggests it is physiologically closer to Black Box than to River Red Gum.

Three eucalypt species dominate the floodplains of the Murray-Darling Basin: River Red Gum *Eucalyptus camaldulensis*, Black Box *Eucalyptus largiflorens* and Coolibah, *Eucalyptus coolabah.* A rough guide to the distribution of these species is that River Red Gum is widespread, Black Box occurs in the south and west, and Coolibah in the north and west of the Basin.

Other tree species

Another dominant tree, but with a smaller distribution, is River Coobah *Acacia stenophylla*. River Coobah woodland occurs patchily though the western part of the Basin, for example, on the Chowilla floodplain, the lower Lachlan river valley, the Gwydir floodplain and on the Paroo system.

Other native trees occur in these floodplain forests and woodlands, and these add floristic and structural diversity. Several of these tree species have a distribution that appears more restricted than River Coobah. For example, there are some which occur mainly beside the main river channel: Silver Wattle *Acacia dealbata* occurs on the upper and mid-River Murray floodplains and River Oak *Casuarina cunninghamii* occurs beside the Murrumbidgee and Lachlan Rivers and some northern rivers; some are associated with specific but patchy soil types, such as *Melaleuca* sp. on the lower Murray floodplains; and some are restricted to specific tributary floodplains such as Yapunyah *Eucalytpus ochrophloia* in the extreme north and west.

Tree species can also grow within the channel, such as Weeping Bottlebrush *Callistemon viminalis* or River Bottlebrush *Callistemon sieberi* and may sometimes have an important geomorphological role. *Melaleuca* sp., establishes on incipient benches within the river channel of the upper Darling River, causing localised sediment deposition (Woodyer 1978).

The most significant non-native tree species in the riparian zone and on the floodplains of the Murray-Darling Basin are the willows, *Salix* spp., which are widespread. Over 100 species or varieties have been introduced to Australia, and their field identification is challenging (see Cremer 1995).

Maintenance

The lowland floodplains where these riparian and floodplain trees grow are in arid and semi-arid zones, areas of low rainfall and high evaporation, thus growing conditions alternate between very dry and very wet. In physiological terms this means trees alternate between drought or heat stress, and threat of water-logging or anoxia in the root zone.

Roots require oxygen, thus prolonged flooding stresses trees because soil oxygen becomes depleted. The time taken for oxygen to become depleted in the root zone to occur depends partly on the soil properties (particle size and packing, hydraulic conductivity), partly on tree species and growth stage (root characteristics, species physiology, root respiratory demand) and partly on water regime (duration of flooding, season, time since last flooding). Most of these are not well known or documented, and (at least for soils) are spatially heterogeneous. The time required for trees to become oxygen-stressed due to water-logging can only be loosely based on field observations.

For established riparian trees, the critical aspects of water regime are frequency and duration of flooding, the duration of the dry period between floods, and the variability of this. Australian rivers have a highly variable flood regime and riparian trees are adapted to this, with some capacity to survive extreme conditions of flood or drought.

Note, however, that prescribing a watering regime based on extreme conditions (ie based on extremes of drought tolerance or flood tolerance) is not good practice. Although this would be tolerated initially, it can be expected to have a cumulative effect that is negative.

Regeneration

Successful regeneration of floodplain trees tends to follow major floods. This is because, at least in natural conditions, it is only after major floods that there is enough surface and sub-surface soil moisture to ensure widespread seedling establishment, and when grazing pressure (stock, rabbits) is reduced. According to one estimate, there have been only six times between 1880 and 1970s when there was widespread regeneration of River Red Gum in the middle reaches of the River Murray (Dexter 1978). Post-flood regeneration often occurs in the “trash line” (organic particles, mainly twigs, but including seeds and other propagules) left by the flood water. The trash provides a protective organic mulch for the germinating seedling. It is common for bands of even-aged trees to mark the extent of specific floods.

Where the overstorey is cleared, or plant competition otherwise reduced, regeneration can be so substantial as to be considered locally a nuisance. The critical question for floodplain trees, as for trees elsewhere in Australia, is whether regeneration is occurring often enough and widely enough to maintain whole populations. A related question is, What is an appropriate age structure for a given population?

Individual plants may establish in other years, for example after minor floods or even following rainfall in run-on areas.

Critical aspects of flood regime for tree regeneration are frequency, duration, magnitude (flood peak), and timing. A flood provides the opportunity for regeneration, but is only the first step in a specific sequence of conditions needed to ensure that seedlings can establish. Prolonged favourable growing conditions following the inundation are needed if the seedling is to avoid desiccation; these ensure that a root system develops that is deep enough or extensive enough to supply the young tree in the following dry period. Thus flood duration and magnitude, as well as timing (eg w.r.t. following conditions, whether cooler or rainy versus hot and dry seasons) influence whether seedlings establish, and flood characteristics in the following year influence the survival of those seedlings that do establish.

Under European settlement, land management is as important a factor in successful generation as water management. Seedlings and saplings are vulnerable to grazing: rabbits, stock, and goats have been implicated, as well as kangaroos. Rabbits are thought to have had a major impact on Barmah Forest (Chesterfield 1986), limiting the effectiveness of good opportunities for regeneration and impacting adults during droughts.

The intended value of a flood – for example, for regeneration – can be lost if land management is not co-ordinated with water regime.

REFERENCES

Chesterfield, E.A. (1986). Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Aust. For*. **49**:4-15.

Cremer, K. W. (1995). *Willow identification for river management in Australia*. Technical paper No 3. CSIRO Division of Forestry, Canberra, Australia.

Dexter, B. D. (1978). Silviculture of the river red gum forests of the central Murray floodplain. *Proc. Roy. Soc. Vic.* **90**:175-191.

Heinrich, P. (1990). *The eco-physiology of riparian River Red Gum (Eucalyptus camaldulensis).* Final Report. Australian Water Resources Advisory Council. October 1990.

McEvoy, P.K. (1992). *Ecophysiology of 3 Eucalyptus species on the River Murray floodplain*. Unpub thesis M. For Sci, University of Melbourne.

Specht, R.L. (1994). Biodiversity and conservation. In: "Australian Vegetation" (ed R.H.Groves). Second edition. Cambridge University Press, Cambridge.

Woodyer, K.D. (1978). Sediment regime of the upper Darling. *Proc. Roy. Soc. Vic* **90**; 139-148.

River Red Gum

Eucalyptus camaldulensis

River Red Gum *Eucalyptus camaldulensis* is one of the best known, most widely used and most widespread tree species in Australia. For a general description of this species, see monographs such as Boland *et al.* (1987).

River Red Gum forms extensive forests in the middle reaches of the Murray and Murrumbidgee Rivers. Elsewhere, it tends to be restricted to a narrow riparian fringe lining the main channel and have an open woodland form, or else forms dense patches on low-lying spots such as inside bends, and on some floodplains. See Beadle (1981), for a general description of River Red Gum woodlands and watercourse fringes from a range of habitat types across semi-arid Australia, and their associated shurbs and understorey species.

River Red Gums grow across a range of flood conditions, even within a single floodplain. This is evident in the range of tree heights recorded. For example, in Barmah Forest, River Red Gum typically ranges from about 15 to 33 metres tall, with height increasing as flood frequency-duration increases (eg Bren and Gibbs 1986).

Australian studies

River Red Gum has been valued as a forestry tree and as a source of timber for over 100 years, and much of the knowledge about the species and its growth is production-oriented. Ecological studies are recent, and mainly based on field studies in the Barmah-Millewa-Gulpa forest complex on the mid River Murray. These ecological studies are diverse, including herbivory (eg Stone and Bacon 1994a, 1994b), litterfall (Briggs and Maher 1983), leaf leaching and ageing (Baldwin 1999). There have been numerous studies on provenances (eg Gibson *et al*. 1994), as well as on salt tolerance and related physiology (eg Marcar 1993).

River Red Gum forests are now recognised as being important in the healthy functioning of lowland rivers. Their functional role has been established through studies of litterfall, carbon form and flux, and of River Red Gums as habitat for a range of aquatic and floodplain fauna.

Use

River Red Gums are used extensively in small-scale and large-scale plantations, as wood lots to treat water or to lower ground water (eg Morris *et al.* 1998). Physiological studies of tree water use from such plantations, often involving saline groundwater, supplement knowledge of River Red Gums under natural conditions.

Note that many of these studies have been carried out on young stands in plantations less than 20 years old, rather than on mature trees. Prior to extrapolating such studies to field conditions, it is useful to remember that stand age, density and size may modify findings.

Phenology

In the Barmah Forest area, flowering in most years is in late spring to mid-summer, and generally follows flooding. Reproduction, as indicated by litter traps catching fallen fruits, is concentrated in summer. Seed fall is about 9 months after flowering ends and peaks in spring (Dexter 1978).

Reproductive effort varies between years and is greater when flooded after a dry phase than if continuously wet (Briggs and Maher 1983). Leaves may be shed to reduce transpirational load in the canopy. Thus leaf fall, which is also variable between years, tends to be greatest in a wet growing season immediately after a dry phase (ie during a growth flush) or during a drought (Briggs and Maher 1983).

Maintenance

Flooding is one of the three sources of water for riparian trees such as River Red Gums, the others being groundwater and rainwater.

Survival during extended dry periods (ie in absence of flooding) is determined by availability (or non-availability) of groundwater, and a reduction in canopy water use, rather than physiological tolerance of water stress.

River Red Gums at Barmah have 'sinkers', that is roots that penetrate deep >10 m into the sub-soil to sandy aquifers (Bren, unpub., Bacon *et al.* 1993). Canopy water use is reduced by leaf-shedding, which reduces leaf area and hence reduces water demand. Under dry conditions, when transpiration is reduced, leaf shedding also reduces heat load: under moist conditions, transpiration cools leaves by as much as 1-3^{o}C (Gibson *et al.* 1994). River Red Gums in Barmah Forest have survived extremely dry conditions such as lack of surface flooding for approximately 18 months, as in the 1982 drought. Historical analysis shows similar periods have occurred about four other times over the last one hundred years, in 1904, 1915, 1944 and 1967 (Bren 1987). The cumulative effect of repeated dry spells, for example at more frequent or for longer periods, is unknown.

In some circumstance, and on some floodplains, River Red Gums may be largely dependent on water other than flood (surface) water, notably groundwater and/or ponded surface water. The degree of dependence varies through time, especially in relation to flood cycles, as has been established by a concerted effort on the Chowilla floodplain, South Australia.

The Chowilla floodplain is dissected by several channels and anabranches; as a result of river regulation, many channels now flow permanently and the groundwater has risen by 2-3 metres. The floodplain is underlain by a relatively shallow (2-4 m) but saline (up to 20 to 60,000 mg L^{-1} TDS) unconfined aquifer (Jolly 1996). River Red Gums on the Chowilla floodplain show a degree of ecological flexibility, as studies have shown they have the ability to switch between different water sources, and to use water of differing quality (ie salinity) (Mensforth *et al.* 1994).

This flexibility was initially demonstrated in field studies on the Chowilla floodplain, South Australia (Thorburn and Walker 1994, Thorburn *et al*. 1994), but has since been demonstrated in plantation studies exploring species performance (eg Morris *et al.* 1998).

River Red Gums fringing the main river channel or floodplain anabranches sourced only about 30-50% of their water from these surface channels (Thorburn and Walker 1994), indicating a partial reliance on groundwater. Trees further out on the floodplain and further from permanent anabranches used mainly groundwater. Even if groundwater was saline, trees beside relatively fresh permanently-flowing anabranches did not solely rely on anabranch water (Thorburn *et al.* 1994). Clearly, it is not possible to assume a single behaviour for all trees or all positions on the floodplain.

The most detailed and precise information about surface water (flooding) comes from the Barmah Forest.

Current flood frequency for most of the River Red Gum forest at Barmah is about 6-8 years in every 10, on average (Bren and Gibbs 1986). Historical analyses of flood records shows that forest trees used to (prior to Hume Dam) experience inundation for 1-7 months and that this occurred primarily in winter-spring. There is increasing evidence that duration is as important as frequency, in terms of whole-forest growth responses. For trees that have been through a dry phase, frequent short floods and longer floods both reduce water stress and hence result in greater growth (Bacon *et al*. 1993). As a result of regulation of the River Murray, flood duration has generally decreased, by up to 1 month, and variability, at least in respect to seasonal timing, has increased (Bren 1987). The changes in flow regime and the detrimental effects on the forest prompted studies on the value of top-up floods.

River Red Gums are an opportunistic user of water, transpiring heavily when water is available (Heinrich 1990). Canopy water use, as indicated by upward flux, shows only relatively little seasonal pattern when conditions are nearly uniform, such as for plantation trees over shallow but saline groundwater (Morris *et al*. 1998). As already indicated, trees that have been constrained by lack of water will grow in response to flooding, thus tree growth (ie wood production) is greatest when flooded under warm conditions such as summer; wood production increases with increasing flood duration (Robertson *et al.* 2000).

Note, however, that when ‘designing’ a water regime for a River Red Gum forest that the requirements of other species will need to be considered.

The effect of seasonal flooding on established River Red Gum increases quantity of growth without altering species composition, but this is not true for understorey species or for tree seedlings. These have seasonal responses which can lead to changes in community composition and in forest structure (Robertson *et al.* 2000, Bren 1992).

The rate of penetration of surface water (flood or rainfall) into the subsoil and hence down into the root zone is influenced by soil properties and subsoil heterogeneity, making flood duration and flow-water distribution critical factors in forest watering, especially after a long dry spell. Shallow forest watering, when floodwaters are confined to flood channels, can be ineffective if flood durations are too short. For example, in the Millewa forest, a 30-45 day summer flood in ‘flood runners’ was effective in wetting the subsoil of nearby trees (within 7.5 metres) but not the subsoil of trees 38 metres away (Bacon *et al.* 1993): if floods were longer (60-80 days in spring), there was no evidence of this distance effect. The same study also showed that floods can be too short, ie that the beneficial effects of short-term flooding are themselves short-term. Within 40 days of flood recession, soil water storage had returned to pre-flood levels, presumably having been lost through rapid transpiration, or downward or lateral infiltration (Bacon *et al.* 1993).

At Barmah, River Red Gums are known to have tolerated relatively long periods of continuous flooding, estimated as 24 months (Bren 1987). This has happened at least twice in very wet periods, once in the mid-1950s and once in the mid-1970s. This estimate of 24 months is consistent with several field observations of about 2-4 years of continuous flooding, before trees show signs of stress. Trees behind Hay Weir apparently survived 3-4 years continuous inundation (Bren 1987); River Red Gums at Murrumbidgil Swamp on the Lachlan River which were flooded continuously between 1974 and 1977 showed no signs of stress worth reporting (Briggs and Maher 1983)in that time; four 4 wet years killed off some low-lying trees in Barmah Forest (Chesterfield 1986). Variations in these estimates and in field observations are due to differences and patchiness in soil properties, air spaces and in root respiratory demands.

Regeneration

Germination and establishment are greatly enhanced by the right flood conditions, but are not dependent on flooding. The critical stage in stand regeneration is seedling establishment, rather than germination; and within this, the critical step is seedling survival to and through the following summer.

Germination can happen without flooding if winter is wet, however winter seedlings are then susceptible to frosts. If seedlings survive this but conditions continue dry, then moisture stress in the following summer is likely, as well as 'girdling' (heat injury to the seedling caused by high temperatures at the soil surface). These are minimised if the summer is cool or rainy.

Flood timing affects germination success. Winter floods with winter recession means seeds experience water and air temperatures which are unfavourable. Spring-summer floods followed by summer recession provide suitable germination conditions but subsequent heat & water stress can cause massive seedling mortality. Regeneration is optimised if flood recession is in spring-early summer, as this results in 'prolific' germination (Dexter 1978).

During the establishment phase, the seedling is vulnerable, both to heat stress and to immersion. Seedlings cope with heat stress by accessing soil moisture, and for this they allocate resources to root growth and extension. Thus seedlings up to about 23 cm tall have roots which are about 4 times plant height, thus giving good penetration into the sub-soil. In addition, seedlings develop some resilience early: seedlings 15 cm tall can shed leaves and recover from axillary buds.

Adaptations that help to protect seedlings from consequences of anoxia resulting from soils being flooded include the development of adventitious roots, and the development of aerenchymatous tissue (Heinrich 1990). Complete immersion, unless brief, is likely to kill seedlings; lower leaves of small saplings die if submerged for long periods.

In general, tolerance of flooded conditions increases as seedlings become established, as root system extends and as sapling height increases. Thus 2-month old seedlings can survive waterlogging for one month with no obvious effect on leaf height and leaf number (Marcar 1993). Seedlings 50-60 cm tall can survive extended flooding, of 4-6 months and complete immersion for few weeks, by shedding leaves (Dexter 1978).

REFERENCES

Bacon, P.E., Stone, C., Binns, D.L., Leslie, D.J. and Edwards, D.W. (1993). Relationships between water availability and *Eucalyptus camaldulensis* growth in a riparian forest. *J. Hydrology* **150**:541-561.

Baldwin, D.S. (1999). Dissolved organic matter and phosphorus leached from fresh and 'terrestrially' aged river red gums leaves: implications for assessing river-floodplain interactions. *Freshwater Biology* **41**:675-685.

Beadle, N.C.W. (1981). *The vegetation of Australia*. Cambridge University Press, Cambridge.

Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleinig, D.A. and Turner, J.D. (1987). *Forest Trees of Australia*. Fourth edition. Nelson-CSIRO, Melbourne.

Bren, L.J. (1987). The duration of inundation in a flooding river red gum forest. *Aust. For. Res*. **17**:191-202.

Bren, L.J. (1992). Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. *Aust. J. Ecology* **17**:395-408.

Bren, L.J. and Gibbs, N.L. (1986). Relationships between flood frequency, vegetation and topography in a river red gum forest. *Aust. For Res* **16:**357-70.

Briggs, S.V. and Maher, M. T. (1983). Litter fall and leaf decomposition in a River Red Gum (*Eucalyptus camaldulensis*) swamp. *Aust. J. Bot* **31**:307-316.

Chesterfield, E.A. (1986). Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Aust. For.* **49**:4-15.

Dexter, B.D. (1978). Silviculture of the River Red Gum forests of the central Murray floodplain. *Proc. Roy. Soc. Vic* **90**:175-194.

Gibson, A., Bachelaard, E.P. and Hubick, K.T. (1994). Growth strategies of *Eucalyptus camaldulensis* Dehnh. at three sites in northern Australia. *Aust. J. Plant Physiol*. **21**:653-62.

Heinrich, P. (1990). *The eco-physiology of riparian River Red Gum (Eucalyptus camaldulensis)*. Final Report. Australian Water Resources Advisory Council. October 1990.

Jolly, I.D. (1996). The effects of river management on the hydrology and hydroecology of arid and semi-arid floodplains. In: M.G. Anderson, D.E. Walling and P.D. Bates (eds). "Floodplain Processes". John Wiley and Sons Ltd.

Marcar, N.E. (1993). Waterlogging modifies growth water use and ion concentration in seedlings of salt-treated *Eucalyptus camaldulensis*, *E. tereticornis*, *E. robusta* and *E. globulus*. *Aust. J. Plant Physiol*. **20**:1-13.

Morris, J., Mann, L. and Collopy, J. (1998). Transpiration and canopy conductance in a Eucalypt plantation using shallow saline groundwater. *Tree Physiology* **18**: 547-555. (Abstract only).

Mensforth, L.J., Thorburn, P.J., Tyerman, S.D. and Walker, G.R. (1994). Sources of water used by riparian *Eucalyptus camaldulensis* overlying highly saline groundwater. *Oecologia* **100**:21-28.

Robertson, A.I., Bacon, P. and Heagney, G. (2000). The responses of floodplain primary production to flood frequency and timing. *J. Appl. Ecology* (in press).

Stone, C. and Bacon, P.E. (1994a). Relationship among moisture stress, insect herbivory, foliar cineole content and the growth of river red gum *Eucalyptus camaldulensis*. *J. Appl. Ecology* **31:**604-612.

Stone, C. and Bacon, P.E. (1994b). Insect herbivory in a River Red Gum (*Eucalyptus camaldulensis* Dehnh.) forest in southern New South Wales. *J. Aust. Ent. Soc*. **33**:51-56.

Thorburn, P.J., Mensforth, L. and Walker, G.R. (1994). Reliance of creek-side river red gums on creek water. *Aust. J. Mar. Freshwater Res*. **45**:1439-43.

Thorburn, P.J. and Walker, G.R. (1994). Variations in stream water uptake by *Eucalyptus camaldulensis* with differing access to stream water. *Oecologia* **100**:293-301.

Black Box

Eucalyptus largiflorens

Black Box *Eucalyptus largiflorens* is a small to medium tree forming open woodlands on floodplains, mainly in the southern and western parts of the Murray-Darling Basin (Boland *et al.* 1987). It also occurs as a fringe to ephemeral and intermittent wetlands, and along water courses (Beadle 1981). The tree is useful for timber but its open form, low-level branching, twisted trunk and slow growth mean it is not a commercial species. For a general description of Black Box woodland and associated shrub and understorey species, see Beadle (1981).

Australian studies

Even though Black Box woodlands are extensive and characteristic of western New South Wales, the ecology of this tree is not as well known as commercially important species, River Red Gum, and are limited, to seedling survival (Treloar 1959) and insect herbivory (Stone and Bacon 1995). Physiological studies are much more extensive, covering various aspects of plant water relations, transpiration and water use (eg Jolly and Walker 1996), and growth models (Slavic *et al*. 1999a, 1999b), mainly in relation to the Chowilla floodplain.

The importance of Black Box trees and woodlands as habitat is not much acknowledged but on the Chowilla floodplain, the woodland is significant for ground-foraging and hollow-nesting avifauna (O'Malley and Sheldon 1990).

Habitat and Growth

Black Box can grow in a range of conditions, and this is reflected in the range in height, form and canopy density found on one floodplain. On the Chowilla floodplain, for example, tree height on an increasing flood frequency gradient ranges from 3 to 21 metres for individuals (Palmer and Roberts 1996) and 6.2 to 12.8 metres for groups at specific sites (Akeroyd *et al*. 1998).

Particularly under drier and less frequently-flooded conditions, the form of Black Box trees is a summary of its history. Its twisted shape, with dead limbs and hollows provide refuge, breeding holes and crevices for birds, lizards and small mammals. The very erect and vigorous forms found at well-watered sites such as beside a weir pool, are usually a product of altered water regime.

Black Box effectively excludes salt from its root systems but this has the additional effect of reducing transpiration (Streeter *et al.* 1996) which can be expected to constrain rates of photosynthesis.

Phenology

Main flowering period for Black Box is August to January (Boland *et al.* 1987) although on the Chowilla floodplain it is much earlier, May-October (Roberts, unpub. data).

Maintenance

Black Box are tolerant of flooding and of drought. Mature Black Box trees differ from River Red Gums in being less tolerant of flooding but more tolerant of prolonged dry conditions. Hence Black Box woodlands occur higher on the floodplain than River Red Gum, and Black Box woodlands are the major floodplain vegetation in western drier parts of the Basin.

Black Box trees are quite drought hardy. Adaptations and characteristics that favour growth and survival under dry and droughted conditions include very low transpiration rates (0.3 to 1 mm per day), and small canopy leaf area and pendulous leaf habit reduce water demand (Jolly and Walker 1996, Streeter *et al.* 1996).

Research on the Black Box woodlands of the Chowilla floodplain has found that Black Box is ecologically flexible and opportunistic in its water use. It can use water from throughout the soil profile, and can use water that is saline. This opportunistic character is where it sources water and what water quality is used is recognised as being an energy-effective strategy (Jolly and Walker 1996). However, in the absence of floods, ie during long interflood periods, Black Box trees must rely on soil water.

The capacity to combine different sources of water, or to switch rapidly from one water source to another does not happen instantaneously: if there are no roots at that level, then a root network must develop. No increase in transpiration was detected after a summer flood because trees were still using soil water from a previous heavy rain event which had re-charged soil (Jolly and Walker 1996). Sensitivity analysis has shown that the main controls on water uptake were depth to groundwater and salinity of groundwater, rather than soil properties (Jolly 1996).

Critical aspects of water regime are flood frequency and flood duration, and their inter-dependence. A rapid survey of nine non-riverine wetland depressions in south-western New South Wales found Black Box trees were healthy where they were flooded for 4-6 months every 4-5 years; but where water had been ponded twice, for 12-18 months, trees were dying (Shepheard 1992). On the Chowilla floodplain, the natural flood frequency for Black Box, as determined by historical flow analysis (Sharley and Huggan 1995) was 1:2 to 1:5 and the natural duration was 2-4 months. For this area, the effect of river regulation has meant a 3-fold reduction in flood frequency (Jolly 1996). This chronic reduction in flood frequency across the floodplain has changed the salinity-hydrologic balance, and the resulting accumulation of salt in the soil profile and at the soil surface has caused tree deaths.

The inundation time tolerated by Black Box trees can be inferred from patterns in tree water use, assuming that a reduction in transpiration indicates root-zone anoxia. Based on this approach, Black Box trees on the Chowilla floodplain can tolerate at least 32 days continuous flooding (Jolly 1996), or as much as 78 days (Akeroyd *et al.* 1998). These tolerance times may be site (or soil) specific: the Chowilla soils are sodic heavy clays. Continuous flooding for 13 months caused acute stress in Black Box trees at Nearie Lake, with yellowing of the canopy (Briggs and Townsend 1993).

Regeneration

Large-scale regeneration occurs after floods (Treloar 1959), as it is after flood recession that suitably moist conditions occur that ensure widespread germination and successful seedling recruitiment. In western New South Wales and on the lower Darling, germination is most effective if it occurs during the winter months, May to October. On the lower and mid-River Murray, floods used to occur mainly in spring giving seedlings the moist conditions going into summer.

Two-month old Black Box seedlings can tolerate flooding (not submersion) for about a month (Heinrich 1990) but growth is reduced if flooding lasts for much longer: seedlings flooded for 70 days showed signs of stress.

The roots of seedlings have low respiratory oxygen demand thus soil oxygen 'lasts' longer. Unlike River Red Gum seedlings, Black Box seedlings have no significant adaptions for tolerating anoxic conditions in the root zone resulting from surface flooding, such as aerenchyma or adventitious roots (Akeroyd *et al*. 1998).

REFERENCES

Akeroyd, M.D., Tyerman, S.D., Walker, G.R. and Jolly, I.D. (1998). Impact of flooding on the water use of semi-arid riparian eucalypts. *J. Hydrology* **206**: 104-117.

Beadle, N.C.W. (1981). *The vegetation of Australia*. Cambridge University Press, Cambridge.

Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleinig, D.A. and Turner, J.D. (1987). *Forest Trees of Australia*. Fourth edition. Nelson-CSIRO, Melbourne.

Briggs, S. and Townsend, G. (1993). *Restoration and management of Nearie Lake*. Final Report, Project N209, Natural Resources Management Strategy. October 1993.

Heinrich, P. (1990). *The eco-physiology of riparian River Red Gum (Eucalyptus camaldulensis)*. Final Report. Australian Water Resources Advisory Council. October 1990.

Jolly, I.D. (1996). The effects of river management on the hydrology and hydroecology of arid and semi-arid floodplains. In: M.G. Anderson, D.E. Walling and P.D. Bates (eds). "Floodplain Processes". John Wiley and Sons Ltd.

Jolly, I.D. and Walker, G.R. (1996). Is the field water use of *Eucalyptus largiflorens* F. Muell. affected by short-term flooding? *Aust. J. Ecology* **21**:173-183.

O'Malley, C. and Sheldon, F. (1990). (editors). *Chowilla floodplain Biological Study.* Nature Conservation Society of South Australia.

Palmer, A.C. and Roberts, J. (1996). *Black box (Eucalyptus largiflorens) on the Chowilla floodplain*. CSIRO Division of Water Resources Technical Memorandum 96.18. October 1996.

Sharley, T. and Huggan, C. (1995). *Chowilla Resource Management Plan*: Final Report. Murray-Darling Basin Commission. March 1995.

Shepheard, M. (1992). *Flooding frequency and Eucalyptus largiflorens (Black Box) wetland health in the Wah Wah district.* Technical Report 92/14. NSW Department of Water Resources.

Slavich, P.G., Walker, G.R., Jolly, I.D., Hatton, T.J. and Dawes, W.R. (1999a). Dynamics of *Eucalyptus largiflorens* growth and water use in response to modified watertable and flooding regimes on a saline floodplain. *Agricultural Water Manage*. **39**:245-264

Slavich, P.G., Walker, G.R. and Jolly, I.D. (1999b). A flood history weighted index of average root-zone salinity for assessing flood impacts on health of vegetation on a saline floodplain. *Agricultural Water Manage*. **39**:135-151.

Stone, C. and Bacon, P.E. (1995). Influence of insect herbivory on the decline of black box (*Eucalyptus largiflorens*). *Aust. J. Bot*. **43:**555-564.

Streeter, T.C., Tyerman, S.D. and Walker, G.R. (1996). Water-use strategies of *Eucalyptus largiflorens*. In: Walker, G.R., Jolly, I.D. and Jarwal, S.D. (eds.) "Salt and water movement in the Chowilla floodplain". Water Resource Series. No. 15. CSIRO Division of Water Resources.

Treloar, G.K. (1959). Some factors affecting seedling survival of *Eucalyptus largiflorens* F. Muell. *Aust. For.* **23**:46-48.

Coolibah

Eucalyptus coolabah

Several *Eucalyptus* species are known as coolibah, but only one, *Eucalyptus coolabah,* is covered here. This is a medium tall tree, occurring in the northern part of continental Australia (eg Beadle 1981). In the Murray-Darling Basin, it forms open woodlands mainly on heavy clay soils in periodically flooded parts of floodplains, mainly in the north and west.

Three distinct subspecies of *E. coolabah* are now recognised. Two are on blacksoil floodplains, subsp. *coolabah* and subsp. *excerata*; one is found on sandier creek soils, subsp. *arida*. Coolibah was formerly known as *Eucalyptus microtheca.*

Australian studies

Published studies covering aspects of species ecology are limited, and refer to trees and sites outside the Basin: a germination study (Doran and Boland 1984) and field description of size classes (Roberts 1993). Floristic decriptions of Coolibah woodlands are given with vegetation maps of northern and western New South Wales (Dick 1993, Pickard and Norris 1994). Associated wildlife has been surveyed on the Culgoa floodplain (Dick and Andrew 1993).

Coolibah woodlands are habitat for smaller terrestrial fauna (Dick and Andrew 1993) such as bats, rodents, dasyurids, as well as birds. Older trees are particularly important: nearly half of the vertebrate fauna on the Culgoa floodplain uses tree hollows as shelter or roost sites, and forage in the canopy.

Dense stands of Coolibah sometimes regenerate after floods, but studies of factors contributing to these (eg role of prior conditions, lack of competition) have not been done. These dense re-growths are considered a problem (eg for mustering) by some affected floodplain graziers (Freudenberger 1998).

Maintenance

Coolibahs tolerate relatively long dry interflood conditions as well as periodic flooding. The floods – and probably also rainfall - re-charge soil moisture. The hot dry conditions that can prevail through the distributional range of Coolibahs are likely to constrain tree growth and canopy renewal to times when conditions are favourable, so, overall, growth can be expected to be pulsed and slightly erratic under natural conditions.

Physiological studies of flooding tolerances, water-strategies, drought tolerances and water stress capacity of field populations of Coolibahs have not been done. Consequently, its natural water regime - frequency, season or duration of flooding – is not well understood, but can be inferred from distribution and flood patterns. However, because Coolibahs occur on different soil types and on different parts of floodplains, descriptions of their water regimes also vary.

For example, coolibahs on the Gwydir system have a long-term average flood frequency about 1 in 10-20 years (Bennett and McCosker 1994). Flooding for Coolibahs associated with floodways is highly variable, probably brief and most likely in summer or autumn (Surrey Jacobs, pers. comm., 2000); this variability could include 2-3 flood pulses each lasting a few weeks in 5 years followed by another 5-year period with no surface flooding. The drought or flood duration that Coolibahs need or can tolerate will be influenced by soil type and is virtually unknown. However, like River Red Gum and Black Box, Coolibahs are intolerant of water-logged soils or permanent flooding. A review of knowledge, value and research needs of Coolibah woodlands has emphasised the need to determine flood responses and water requirements of Coolibahs (Freudenberger 1998).

Regeneration

For Coolibahs, as with other riparian and floodplain species, broad-scale regeneration follows certain flood events (Roberts 1993). In northern NSW, patches of dense re-growth on the Balonne-Culgoa floodplains are linked to wet years of 1890s, mid 1950s, mid 1970s and 1983 (Freudenberger 1998). Specific germination requirements and seedling establishment conditions are not well known, but Coolibahs may be adapted to regenerate after late summer flooding, as germination rates are high at high temperatures (Doran and Boland 1984).

There is a relatively short period between fruit maturation and seed shed, which occurs towards the end of summer indicating no seed storage on the tree.

REFERENCES

Beadle, N.C.W. (1981). *The vegetation of Australia*. Cambridge University Press, Cambridge.

Bennett, M. and McCosker, R. (1994). *Estimating environmental flow requirements of wetlands*. In: Proceedings of Environmental Flows Seminar. 25-26 August 1994. AWWA, Canberra.

Dick, R. (1993). *The vegetation of the Wombeira Land System on the floodplains of the Culgoa, Birrie and Narran Rivers in NSW - November 1990*. Occasional Paper 13, NSW National Parks and Wildlife Service, Hurstville.

Dick, R. and Andrew, A. (1993). *A vertebrate fauna survey of the Culgoa and Birrie River floodplains in NSW 1990-1992*. Occasional Paper 14, NSW National Parks and Wildlife Service, Hurstville.

Doran, J.C. and Boland, D.J. (1984). Effects of temperature on germination of *Eucalyptus microtheca. Aust. For. Res*. **14**:49-55.

Freudenberger, D. (1998). *Scoping the management and research needs of the coolibah woodlands in the Murray-Darling Basin*. CSIRO Wildlife and Ecology, May 1998.

Pickard, J. and Norris, E.H. (1994). The natural vegetation of north-western New South Wales: notes to accompany the 1 000 000 vegetation map sheet. *Cunninghamia* **3**:423-464.

Roberts, J. (1993). Regeneration and growth of coolibah, *Eucalyptus coolabah* subsp. *arida*, a riparian tree, in the Cooper Creek region of South Australia. *Austr. J. Ecology* **18**:345-350.

Summary Sheet: Trees

Maintenance of Established Trees
River Red Gum *Eucalyptus camaldulensis* For southern areas, an average flood frequency of 1-2-3 years; average duration 4-7 months, occurring in winter-spring, and not lasting more than 24 months continuous flooding or 24 months without flooding; duration can be supplemented by summer floods although repeated summer floods will alter the understorey. Flood frequency and duration may need to be reduced if the water table is shallow or trees have access to permanent water. Complete drying between flood cycles is needed or as much as possible, to ensure cracking for soil aeration and deep re-charge.
Black Box *Eucalyptus largiflorens* Flood frequency of 1 in 3 to 5 years with duration from 4 to 2 months, but can tolerate reduced frequencies such as 1 in 7-10 if there is no reduction of flood duration. Flood timing is possibly not critical for maintenance of adult trees. Continuous flooding of floods of 4+ months may appear beneficial, at least initially, but are likely to lead to long-term loss in vigour as soil oxygen gradually becomes depleted.
Coolibah *Eucalyptus coolabah* Distribution patterns suggest an average flood frequency of 1 in 10-20 years, but within this tolerant of temporal variability, and of long periods without flooding. Natural flood duration unknown but is likely to range from a few to several weeks, and vary with soil type. Summer and autumn are the most likely season for flooding, but effects of shifting this seasonal pattern, if any, are not known.
Regeneration
River Red Gum *Eucalyptus camaldulensis* A large flood, extending well into late spring or early summer; followed by wet winter-spring or shallow and brief or pulsed winter-spring floods, and even brief or shallow summer flooding.
Black Box *Eucalyptus largiflorens* Extensive flood long enough to saturate surface soil, with slow recession. Timing of natural regenerating floods was in winter-spring months but it is not known if there are seasonal constraints on germination or seedling growth.
Coolibah *Eucalyptus coolabah* Probably wet soils or shallow flooding in late summer, but no specific details available.

SHRUBS
Shrublands

Shrubs are woody multi-stemmed plants, generally up to 2-3 metres tall. Vegetation where shrubs are dominant are shrublands.

Shrubs may also be part of the understorey in floodplain woodlands and on riverbanks, where they add structural complexity and diversity. A shrub layer is generally lacking from floodplain forests in the southern part of the Basin, except in forest-woodland patches which are rarely flooded and are dominated by terrestrial eucalypts such as Grey Box and Yellow Box patches with Gold-dust Wattle *Acacia acinacea* as understorey (Chesterfield 1986).

Distribution

In drier parts of the Murray-Darling Basin, especially west of the Darling River, shrublands are a conspicuous and dominant part of floodplain vegetation. Thus on the Paroo and Cuttaburra system, shrublands are extensive and relatively diverse, with up to three dominant shrub species (King *et al.* 1995). In contrast, on the River Murray floodplain, shrublands occur only downstream of Barmah (Margules 1990) and are typically dominated by one species, Lignum.

Shrub species

Several species dominate the drier floodplain habitats; Lignum *Muehlenbeckia florulenta*, Spiny Lignum *Muehlenbeckia horrida*, Nitre Goosefoot *Chenopodium nitrariaceum*, Nitre Bush *Nitraria billardieri*, and Old Man Saltbush *Atriplex nummularia*. Of these, the most ecologically significant is Lignum.

Several small and large saltbushes (family Chenopodiaceae) occur as sub-dominants in more saline floodplains. Vegetation descriptions suggest that non-chenopod shrubs are more common in northern part of the Basin than southern areas (Margules 1990, Dick 1993).

The diversity of shrubs in drier areas is largely under-recognised because of a long history of grazing. Stock exclusion on parts of the Chowilla floodplain has encouraged vigorous re-growth of *Eremophila*.

Shrublands are not as aesthetically pleasing as forests and woodlands so have fewer champions, however they are highly signficant as bird habitat, especially for nesting colonial waterbirds.

On riverbanks, shrubs may be refuge as well as habitat; for example, on the River Murray, fish use River Bottlebrush *Callistemon sieberi* as velocity shelters during floods.

REFERENCES

Chesterfield, E.A. (1986). Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Aust. For*. **49:**4-15.

Dick, R. (1993). *The vegetation of the Wombeira land system on the floodplains of the Culgoa, Birrie and Narran Rivers in NSW – November 1990.* Occasional paper Number 13, National Parks and Wildlife Service, Hurstville, NSW 2220.

King, A. M., Green, D.L. and Brady, A.T. (1995). *Wetlands of the Paroo River and Cuttaburra Creek.* Department of Land and Water Conservation. Technical Services Division. TS 95.132. July 1995.

Margules (1990). *Riparian vegetation of the River Murray*. Report prepared by Margules and Partners Pty Ltd., P and J Smith Ecological Consultants, Department of Conservation, Forests and Lands. Murray-Darling Basin Commission, Canberra. January 1990.

Lignum

Muehlenbeckia florulenta

Lignum, *Muehlenbeckia florulenta,* formerly named *Muehlenbeckia cunninghamii*, forms distinctive mono-dominant shrublands that cover large parts of floodplains within the western parts of the Murray-Darling Basin. Lignum also occurs further east, where it is much less extensive, typically occurring as a fringe around ephemeral wetlands and beside temporary creeks, or as scattered individuals, in relict stands.

The shrub has a very distinctive form, being multi-stemmed and usually leafless. It is deep-rooted, and salt-tolerant (Craig *et al.* 1991) and drought-tolerant. Lignum shrublands are quite distinctive.

Australian studies

Ecological knowledge of Lignum is limited to one study (Craig *et al.* 1991), weed control reports and field observations.

When flooded, Lignum is an important nesting habitat for birds such as the colonial waterbirds and freckled duck. Wet or dry, Lignum is habitat for feral pigs. The dense growth that develops after repeated flooding or a flooding sequence can be problematic for stock mustering.

Habitat

Lignum grows on cracking grey clays, typically with crab-holes or gilgais, on sites ranging from frequently to infrequently flooded, the less frequently flooded sites being in areas where there is a greater likelihood of summer rainfall.

At nearly all these natural sites, water is ponded for some time: duration (in this case, time ponded) is therefore as important as flood frequency for Lignum water regime; possibly the best measure for this species is number of wet days.

Growth

Like other floodplain species, Lignum shows a remarkable size and height range in relation to flood regime. Under wetter conditions, Lignum bushes are rounded and dense, 3 metres tall or taller: under dry conditions, bushes are sparse, straggly and short, <0.5 m, with only a few stems. When flooded, the area between Lignum bushes may be an *Eleocharis* sedgeland, an aquatic herbland with Red Milfoil or Nardoo, or a shallow lake.

Maintenance

After long dry spells, Lignum responds quickly to an increase in available water, whether floods or heavy rain, by developing leaves then flowering. The small inconspicuous leaves are soon shed, which is probably a water conservation measure. Stems remain green.

Lignum is possibly more tolerant of drought than flooding. Observations of brown and stunted bushes behind levee banks show that Lignum can survive up to several years in regions with low rainfall with little to no flooding: however, in these cases, its value as habitat is chronically reduced and the long-term effects not sustainable.

In south-western New South Wales, healthy Lignum sites flood, on average every 3 years, but duration was not specified (Scott 1992); in north-western New South Wales, depending on land system, Lignum swamps flood on average an estimated every 1-2 years to ~10 years, for about 6-12 months (Goodrick 1984) and the Lignum-dominated Cuttaburra basin floods about 1 in 3 years, retaining water for as much six months if filled (King *et al.* 1995). In South Australia, Lignum swamps on the Chowilla floodplain originally flooded frequently, every 2-3-4 years with a flood duration of 3-4 months (Sharley and Huggan

1995), but since river regulation this has been reduced to every 3-10 years, by floods now lasting 2-3 months.

Note that for floodplain habitats, estimates of Lignum water requirements can underestimate flood duration if they are based on duration of river peaks as this does not account for ponding.

Lignum is intolerant of sustained or permanent flooding. If its water regime changes from intermittent or seasonal to near permanent, Lignum may initially appear vigorous but the prolonged flooding will eventually result in loss of vigour and eventually death. This can be observed on upstream side of blockbanks or levels on floodplains in south-western New South Wales, for example the Lowbidgee and, to a lesser extent, the lower Mirrool Creek floodplain.

On the banks of the River Murray, SA, Lignum occurs where it floods for 45-115 days per year, usually no more than 60 cm deep (Blanch *et al*. 1999).

Regeneration

Although the germination requirements for Lignum have not been studied, field observations suggest flooding and temperature (or season) are important in both germination and establishment.

Seedlings have been observed only after summer-autumn floods (Roberts, pers. obs.).

REFERENCES

Blanch, S.J., Ganf, G.G. and Walker, K. F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Craig, A.E., Walker, K.F. and Boulton, A.J. (1991). Effects of edaphic factors and flood frequency on the abundance of lignum (*Muehlenbeckia florulenta* Meissner) (Polygonaceae) on the River Murray floodplain, South Australia. *Aust. J. Botany* **39**: 431-443.

Goodrick. G.N. (1984). *Wetlands of north-western New South Wales*. National Parks and Wldlife Service. Occasional Paper Number 6. July 1984.

King, A.M. Green, D.L. and Brady, A.T. (1995). *Wetlands of the Paroo River and Cuttaburra Creek*. Environmental Studies Unit, Department of Land and Water Conservation, Technical Services Division. TS 95.132. July 1995.

Sharley, T. and Huggan, C. (1995). *Chowilla Resource Management Plan*: Final Report. Murray-Darling Basin Commission. March 1995.

Scott, J.A. (1992). The natural vegetation of the Balranald-Swan Hill area. *Cunninghamii* **2**:503-662.

Summary Sheet: Shrubs

Maintenance of Established Shrubs
Lignum *Muehlenbeckia florulenta* Flooding frequency on average every (1)-2-8 years with flooding being more frequent in north-west and less in southern areas; ponding duration is 6-12 months possibly 3-4-5 months. Continuously wet should be avoided. Complete drying to cracking stage between floods is essential to ensure soil aeration, soil water recharge, and to preserve the crack habitat for small native animals. No evidence as to whether season is important; possibly the natural season for flooding was late summer in northern areas, probably earlier, spring-summer, in southern areas.
Regeneration
Lignum *Muehlenbeckia florulenta* Germination requirements not studied. Field observations suggest season may be critical factor with summer floods lasting long enough to wet soil profile; more specific details not known.

GRASSES
Grasslands

Grasses are in the family Poaceae, one of the largest plant families in the world, and one of the most important. Grasses are food for humans and animals, such as cereals, rice and pastures; a source of fibre, such as bamboo. The family Poaceae includes some of the world's major weeds, such as barleygrass.

Grasses are ubiquitous, and native and introduced grass species are found in nearly all riverbank, littoral, riparian and floodplain habitats. Less than 30 exotic grasses were recorded in a survey of a northern floodplain (Dick 1993) compared with approximately 120 (approx 50% introduced) recorded from the River Murray floodplain (Margules 1990).

Only a few species form extensive grasslands in the Murray-Darling Basin: see Beadle (1981) and Briggs (1981) for descriptions of grasslands at high altitudes, arid inland and outside the Basin.

Grassland species

The main grassland-forming species in the Murray-Darling Basin are spiny mudgrass *Pseudoraphis spinescens*, Water Couch *Paspalum distichum*, Common Reed *Phragmites australis*, Canegrass *Eragrostis australasica.* These four have quite distinct habitats and growth-forms. The four include: a tall emergent macrophyte *Phragmites australis*; a medium-tall tussock grasses, *Eragrostis australasica*; and prostrate, decumbent mat-forming grasses such as *Paspalum distichum* and *Pseudoraphis spinescens*.

Other grasses

There are many other aquatic, wetland and riparian grass species but these are less likely to form extensive grasslands, except locally, unless the overstorey is removed. In this case these can be considered as derived grasslands.

Examples of significant grass species from lowland riverine and floodplain habitats include:

Couch *Cynodon dactylon* is flood and drought tolerant, and on the Darling River, it grows towards the top of the riverbank; the opportunistic nature of this species was noted on the Pongolo floodplain in South Africa, where it was able to utilise moisture from oceanic mists (Furness and Breen 1986).

Warrego Summer Grass *Paspalidium jubiflorum*, a widespread species, found on the Murray and Darling River systems and their tributaries; Warrego Summer Grass with Wallaby Grass *Austrodanthonia* spp. and Kangaroo Grass *Themeda australis* is common as an understorey in eucalypt woodland.

Rats Tail Couch *Sporobolus mitchelli* is a riverbank and littoral zone species, similar to Couch, but more common on rivers such as the Lachlan.

Curly Mitchell Grass *Astrebla lappacea* forms a perennial tussock grassland, on floodplains of the Darling River and northern tributaries.

Amphibromus nervosus, a tufted tussock perennial, is more common in floodplain habitats in the southern part of the Basin.

Seeds of Swamp Millet *Panicum decompositum* are important food for some ducks.

Some of these grasses are described in Romanowski (1998).

Abundance and extent

Throughout the Basin, changes in abundance, extent and composition of grasslands and understorey species in aquatic and floodplain habitats are largely due to synergistic effects of altered (usually reduced) flooding regime, grazing (eg Frankenberg 1997) and, in some areas, altered fire regimes.

Most floodplain grasses are palatable but even though they are valued as forage, heavy grazing does occur. Replenishment of rhizome carbohydrate storage typically occurs after aboveground biomass reaches its seasonal peak, that is during flood recession, thus floodplain grasslands would benefit from temporary stock exclusion at this time, as advocated by Ward (1991) for Moira Grass plains in the Barmah Forest.

Despite the importance of floodplain grasses for the grazing industry, there have been very few studies on floodplain species within the Basin. Particularly in northern Australia, there has developed a reliance on introduced grasses, notably as 'ponded pastures'. Several of these are now actual or potential problem species for wetlands in northern Australia.

Water regime: other grasses

Water requirements of the following species is based on observations for north-central Victoria (Ward 1996) and for banks of the River Murray, South Australia (Blanch *et al.* 1999):

Agrostis avenacea: grows quickly after brief flooding or rain particularly in warmer months. Tolerates flooding to 10 cm; optimum water flood duration is 3 months, tolerant of up to 6 months (Ward 1996).

Amphibromus nervosus: tolerates water depths to 50 cm, flood duration of 6-8 months with 7 months optimum (Ward 1996).

Cynodon dactylon: tolerant of flooding and exposure 85-150 days per year, not necessarily consecutively, typically occurring at depths less than 60 cm (Blanch *et al.* 1999). Overseas research suggests this species is drought hardy and that the frequency and duration of flooding are more important aspects of its water regime (Furness and Breen 1986).

Paspalidium jubiflorum: found where flooding occurs for 70-140 days per year, not necessarily consecutive, and where depths are unlikely to exceed 60 cm (Blanch *et al.* 1999).

Sporobolus mitchelli: occurs on riverbanks where it is inundated for 45-150 days per year (periodical total, not continuous), rarely for more than 60 cm (Blanch *et al.* 1999).

REFERENCES

Beadle, N.C.W. (1981). *The Vegetation of Australia.* Cambridge University Press, Cambridge.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Briggs, S.V. (1981). Freshwater Wetlands. In: R.H.Groves (ed.) "Australian Vegetation". First edition. Cambridge University Press, Cambridge.

Dick, R. (1993). *The vegetation of the Wombeira Land system on the floodplains of the Culgoa, Birrie and Narran Rivers in NSW-November 1990*. Occasional Paper No 13, National Parks and Wildlife Service (NSW). Hurstville.

Frankenberg, J. (1997). *Guidelines for growing Phragmites for erosion control*. CRC-Freshwater Ecology and MDFRC, Albury, NSW.

Furness, H.D. and Breen, C.M. (1986). An assessment of the importance of water stress in seasonally flooded *C. dactylon* on the Pongolo River floodplain in the formulation of guidelines for controlled flooding. *Hydrobiologia* **137**:175-184.

Margules (1990). *River Murray Riparian Vegetation Study*. Prepared for the Murray-Darling Basin Commission. January 1990.

Romanowski, N. (1998). *Aquatic and Wetland Plants: a field guide for non-tropical Australia*. University of New South Wales, Press, Sydney.

Ward, K.A. (1991). *Investigation of the flood requirements of the Moira grass plains in Barmah Forest, Victoria*: Final Report. Department of Conservation and Environment, Shepparton, Victoria.

Ward, K.A. (1996). Flood requirements of vegetation for the rehabilitation of Lake Mokoan. (draft document).

Spiny Mudgrass or Moira Grass

Pseudoraphis spinescens

Spiny Mudgrass, *Pseudoraphis spinescens,* forms wet grasslands in open areas where flooding is frequent or nearly annual. Spiny Mudgrass grasslands are also important on some floodplains in northern Australia (Finlayson *et al.* 1990). In the southern part of the Basin, particularly in northern Victoria, Spiny Mudgrass is known as Moira Grass (eg Bren 1992).

Distribution

In the Murray-Darling Basin, grasslands of this species occur mainly in the south, mainly as shallow depressions in Red Gum forests and as an extensive sward in larger billabongs associated with major rivers. In Barmah Forest, these grasslands mostly occur on deep (10 m) heavy lacustrine clays (Bren 1992).

Form

The species is rhizomatous perennial. It has trailing stems, up to 2 metres long, with a short fibrous root system at the nodes. The stems are flexible, and semi-buoyant, and hold the leaves and erect seedhead flower several centimetres above water. Having a flexible and buoyant stem keeps the seedhead above the water, despite wind-induced waves and changes in water level, unless water level changes exceed stem length.

On moist soil after flood recession or during a drying phase, Spiny Mudgrass forms a dense turf (Surrey Jacobs, pers. comm. 2000).

Studies

Ecological studies have been published on seed banks (Finlayson *et al.* 1990), growth responses to flooding (Ward 1991), and records of responses to grazing (Ward 1991).

Phenology

In southern regions, flowering is mainly in mid-summer, November to January, or about one month after stem apex has emerged from the water (Ward 1991). Flowering is mainly on larger individuals. Flowering rates are sensitive to flood timing, with more stems flowering after winter flooding than autumn. Early flood recession causes stems to root at nodes so encourages asexual reproduction rather than seed bank investment.

Maintenance

In the Barmah Forest, Spiny Mudgrass grasslands currently have a near annual flood frequency (3 years out of 4) and flood duration of about 9+ months (Bren and Gibbs 1986), or are flooded in 75% years, for average of 4.9 months, with longest interflood period being 25 months (Bren 1992).

Seasonal changes in flood regime of the River Murray, particularly the decrease in winter flooding and increase in summer flooding, favour the establishment of River Red Gum seedlings, and hence the area of Moira Grass plains is contracting (Bren 1992). Spiny Mudgrass is very palatable to cattle, and variable stocking rates and practices in the past may explain its quirky distribution on floodplains.

Spiny Mudgrass grows rapidly in response to flooding. Shoot extension at rates of 10 mm day in winter and 20 mm day in late spring are known from the Barmah Forest area (Ward 1991). Rapid growth in response to summer flooding has been noted on the Chowilla floodplain, where individual plants with 2 meter long flowering shoots were observed in December, only 4-6 weeks after flooding began (Roberts, pers. obs.). On the Murrumbidgee floodplain, brief flooding in October stimulated growth but was insufficient for flowering. Once leaves are above the water surface, growth behaviour changes from terminal growth to branching.

A minimum flood duration of 5 months, and preferably 7 months, with a minimum depth of 0.5 metres, is needed in the Barmah Forest area, if Moira Grass is to out-compete River Red Gum seedlings (Bren, pers. comm); ideally, floods should be continuous late winter-early spring flooding, and recede before summer as milfoil then takes over. Elsewhere in Victoria, the optimum flood duration is 7 months, with a minimum of 3 and maximum of 10; and flood depths of up to 2 metres are tolerated (Ward 1996).

Regeneration

Germination of Spiny Mudgrass has not been specifically studied so it is not known whether there are temperature thresholds or seasonal requirements. Seed bank studies in northern Australia have found that germination rates are 5-10 times higher when seed banks are moist rather than flooded but germination does occur under shallow water (Finlayson *et al.* 1990). There is indirect evidence that viable seeds can be transported short distances downstream (Finlayson *et al.* 1990).

Vegetative regeneration from fragments and buried nodes may be as important, ecologically, as seed banks, providing plant fragments have not been damaged or removed. The species has some resilience to stock, as trampling can break up dead canopy into fragments (Roberts, pers. obs). When stems are long, they break up easily (Ward 1991); the resulting plant fragments will establish only if dispersed to moist habitats.

REFERENCES

Bren, L.J. (1992). Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. *Austr. J. Ecology* **17**:395-408.

Bren, L. J. and Gibbs, N.L. (1986). The relationship between flood frequency, vegetation and topography in a river red gum forest. *Aust. For. Res*. **16**:357-70.

Finlayson, C.M., Cowie, I.D. and Bailey, B.J. (1990). Sediment seed banks in grassland on the Magela Creek floodplain, northern Australia. *Aquatic Botany* **38**:163-176.

Ward, K. A. (1991). *Investigation of the flood requirements of Moira grass plains in Barmah Forest, Victoria*: Final Report. Department of Conservation and Environment, Shepparton, Victoria.

Ward, K.A. (1996). Flood requirements of vegetation for the rehabilitation of Lake Mokoan. (draft document).

Water Couch

Paspalum distichum

Water Couch *Paspalum distichum* is a rhizomatous perennial. Its habit and growth form varies, depending on water conditions. In shallow water, it develops prostrate trailing stems; these can become erect and up to 1 metre tall under optimum conditions (warm, persistent flooding, no to low grazing pressure). On wet muds or in shallow water, it has a short-medium tall erect form, to 0.5 m, often forming small dense rounded mounds. In drier and more ephemeral areas, it forms a sward.

Water Couch is palatable to cattle and other herbivores, such as buffalo. It can sustain grazing provided it is not water stressed (ie conditions dry), and providing it is not persistently grazed below water level (Middleton 1990). Water Couch grasslands are a valuable resource for floodplain graziers.

The distinctive creeping habit of Water Couch was found to be a preferred habitat for a frog species *Crinia parinsignifera* in a degraded billabong near Wagga Wagga; conversely, the absence of this frog species at an nearby billabong was attributed to the lack of Water Couch, and in turn attributed to cattle grazing (Healey *et al*. 1997).

Distribution

Water Couch has a world-wide distribution. Within Australia, it occurs in a wide range of habitats, natural, modified and man-made (eg irrigation channels and storages), usually as a fringe or as isolated tussocks. In the Murray-Darling Basin, grasslands of Water Couch occur on floodplains of the Macquarie and Gwydir Rivers. Overseas, it is also dominant, forming grassland, eg in monsoonal wetlands in India.

Studies

Studies of ecology and growth of Water Couch in a wetland environment or as a dominant wetland species are rare, despite its cosmopolitan distribution.

In Australia, ecological studies of Water Couch on the Gwydir system have been started but are not yet completed. Obvious differences in climate and unknown differences in genotypes make it difficult to apply knowledge from overseas wetland studies, such as in monsoonal India (eg Middleton *et al.* 1991), to Water Couch grasslands in the Murray-Darling Basin.

Maintenance

In the northern parts of the Murray-Darling Basin, Water Couch requires regular flooding, such as once-twice a year, and can possibly tolerate repeated floods (Bennett and Green 1993). Buried rhizomes and nodes mean it can survive a few years without flooding. However a series of droughts or a protracted drought is likely to lead to a loss in vigour, making it vulnerable to being outcompeted by invasive species that are more tolerant of such drier conditions. This may be happening on the Gwydir floodplain, where an introduced stoloniferous herb, Lippia *Phyla canescens*, has established; however it is likely that grazing is also involved, interactively with reduced flooding.

Water Couch is pre-dominantly a summer-growing species so the timing of floods (ideally, spring and summer) is important. Summer floods should last for 4-8 weeks, and be not less than 10 cm deep (Bennett and Green 1993).

On banks of the lower River Murray, Water Couch is found where flooding occurs for a total of 150-220 days in a year, but probably not consecutively, and mostly where depths do not exceed 60 cm (Blanch *et al.* 1999).

Regeneration

Water couch is summer-flowering. Studies in India found that germination occurred only in moist conditions and was almost completely inhibited when seeds were submersed (Middleton *et al.* 1991). No information on temperature preferences was located.

The growth form and habit of Water Couch suggests that vegetative regeneration from fragments or buried nodes may be important but this has not been reported.

REFERENCES

Bennett, M. and Green, J. (1993). *Preliminary assessment of Gwydir wetlands water needs*. Technical Services Division, NSW Department of Water Resources. TS 93.085. December 1993.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Healey, M. Thompson, D. and Robertson, A. (1997). Amphibian communities associated with billabong habitats on the Murrumbidgee floodplain, Australia. *Australian Journal of Ecology* **22**:270-278.

Middleton, B.A. (1990). Effect of water depth and clipping frequency on the growth and survival of four wetland plant species. *Aquatic Botany* **37**:189-196.

Middleton, B.A., van der Valk, A.G., Mason, D.H., Williams, R.L. and Davis, C.B. (1991). Vegetation dynamics and seed banks of a monsoonal wetland overgrown with *Paspalum distichum* L. in northern India. *Aquatic Botany* **40**:239-259.

Common Reed

Phragmites australis

Common Reed *Phragmites australis* is a cosmopolitan grass species, ie has a world-wide distribution; it is also one of the best-known wetland plants. Although called Common Reed, it is most often referred to by its Latin name, *Phragmites*, which means 'hedge'. The species was formerly known s *Phragmites communis* Trin. and this name is used in the earlier scientific literature.

Appearance and Growth

Phragmites is a tall (2-5 metres) perennial rhizomatous emergent macrophyte. It can form dense stands, with over 200 stems m^{-2}; this can be more than doubled, 400-600 stems m^{-2} if the stand is grazed or fired. The height (and density) of *Phragmites* stands is influenced by its environment, and shoots are generally shorter under nutrient-poor and/or water-limiting and/or under grazing pressure conditions. Stems, especially when young, are palatable to stock.

Phragmites overseas

In Europe, there has been such a widespread decline in *Phragmites australis* and such international concern there, that a major international (European) research program was set up, called EURREED. This has resulted in a huge literature and major advances in knowledge of *Phragmites* physiology, especially in areas such as nutrient uptake kinetics, root-rhizosphere aeration and rhizome biology, as well as genetics and ecotypic variations. In parts of the USA, in contrast to Europe, *Phragmites* is an invasive species, particularly in coastal Louisiana (Chambers *et al.* 1999).

Water regime studies

Despite this research effort, and the links between *Phragmites* die-back and the combination of eutrophication (and litter accumulation) and regulated water levels (Clevering and Lissner 1999), knowledge of *Phragmites* water relations and water regime is limited. The links between water regime and plant vigour or life history are not much considered in the current debate on reed decline in Europe, which is perhaps an oversight (Rea 1996).

The few studies that have been done, are from cool temperate European countries such as Romania and Britain (eg Haslam 1970). These studies are hard to relate to Australian conditions because of climatic differences, and because of the potential ecotypic differences.

Ecotypic differences are recognised in Europe, where most plants are tetraploids (4x). Although differences in ploidy level do not automatically imply ecotypic differences, tetraploids are generally more salt tolerant than octoploids (Clevering and Lissner 1999). *Phragmites* in most river catchments in south-eastern Australia is octoploid (8x), with occasional decaploids (10x), for example on the Murrumbidgee River (Clevering and Lissner 1999).

Distribution in Australia

In the Murray-Darling Basin, *Phragmites* forms discontinuous fringe beside inland rivers in the southern and central regions. Its abundance has been much reduced due to combined effects of high summer flows and stock grazing. Extensive monospecific stands occur in well-watered terminal floodplains on the Lachlan and Macquarie Rivers, in the Great

Cumbung Swamp and the Macquarie Marshes respectively. Common Reed probably once dominated the low-lying and more frequently-flooded parts of other floodplains, such as Barmah Forest, the upper Murray (Frankenberg pers. comm.) and possibly much of the Lowbidgee (Roberts 2000).

Australian studies

Australian studies on *Phragmites australis* are limited to growth and biomass studies (Hocking 1989a, 1989b), and function as a bank stabiliser (Frankenberg and Tilleard 1991), and a catchment-scale assessment of changes (Roberts 2000).

Phenology

In southern-eastern Australia, under saturated conditions, the plant reaches maximum canopy biomass in mid-late summer (Hocking 1989a), flowers in late summer but seed is not ripe and ready for dispersal until autumn. In Britain, it grows best after a spring flood (Haslam 1970).

Maintenance

According to Weisner and Strand (1996), rhizome architecture of *Phragmites* in northern Europe varies with water depth; in shallow water areas, rhizome is deeper, and in deep water areas rhizome is shallow. This could mean that dramatic changes to water regime could affect plant vigour.

British studies suggest *Phragmites* tolerates a maximum depth of 0.75 to 1.5 m, and suggests this may be deeper in warmer climates (Haslam 1972). The plant is tolerant of being overtopped in floods, although prolonged immersion will kill stems. It is also tolerant of fluctuating water levels, and can survive dry conditions. Specific durations for any of these are not known.

Phragmites does not require flooding to survive, only adequate water. In non-riverine systems, established stands can survive on groundwater alone, as on some spring-fed soaks (Judy Frankenberg, pers. comm. 2000).

Survival over long dry periods is possible because of the deep (1-2 metres) rhizomes: these appeared to be cause of its regeneration (as opposed to germination from seed) after flooding in the Macquarie Marshes after a long drought. As with most emergents, combination of water depth, duration and timing are critical factors, but these have not been pieced together in a useful model form. Each parameter has been diagnosed separately.

For *Phragmites*, growth is most vigorous when the water is only a few centimetres deep (Ostendorp 1991). The lower limits of Phragmites are defined by its capacity to oxygenate its rhizosphere, usually considered to be water depth of 1.5-2.0 metres. The upper limit, above the waterline, is much harder to define, and is influenced by timing of water level in relation to the growing season and by tolerance of dry conditions. Thus this is affected by climate, soil type, bank angle. From an Australian view, the overseas studies are limited because they concentrate on distribution at the lower end of the range (eg Ostendorp 1991).

On the banks of the River Murray in South Australia, *Phragmites* occurs where flooding occurs for 80-225 days per year, not necessarily consecutive days, and mostly where depth is less than 60 cm (Blanch *et al.* 1999).

Regeneration

Re-generation from seed is rare in long-lived clonal plants, such as *Phragmites*, and is most likely after a drawdown, or other extreme event. Re-establishing canopy populations by re-growth from rhizomes is much more likely.

Seeds are viable for 3-4 years (Haslam 1972) or an estimated 2-3 years at least (Frankenberg pers. comm.). Germination is slow (3-4 weeks) at winter temperatures but rapid, 6-7 days, at temps over 25^{o}C, provided seeds are kept under moist (but not submerged) conditions (Frankenberg 1997). Ripe seeds can float for 2-3 days before sinking (Coops and van der Velde 1995).

Seed set in the inflorescence can be poor, despite apparently vigorous flowering, and varies from year to year (Judy Frankenberg, pers. comm. 2000). Some populations rarely set seed; seed set is reduced in stressful conditions.

Lag time between being submerged and the start of germination is longer for *Phragmites* than for other emergent macrophytes: *Phragmites* takes 10 days, compared with only 4-5 days for *Typha* spp. in the Netherlands. Seeds germinate better in moist rather than saturated or submersed conditions. Seedlings are intolerant of being submersed, with growth (leaf extension) soon ceasing (Haslam 1972). Although submersed leaves of seedlings can photosynthesise, it is at a very low rate. Two-week old seedlings do not grow well under water, even 0.2 m, unlike *Scirpus lacustris* (Weisner *et al.* 1993).

Although *Phragmites* can re-grow from nodal rhizome fragments, the pattern of clonal diversity in European lakes suggests vegetative dispersal is rare (Clevering and Lissner 1999).

REFERENCES

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Chambers, R.M., Meyerson, L.A. and Saltonstall, K. (1999). Expansion of *Phragmites australis* into tidal wetlands of North America. *Aquatic Botany* **64**:261-274.

Clevering, O. A. and Lissner, J. (1999). Taxonomy, chromosome numbers, clonal diversity and population dynamics of *Phragmites australis*. *Aquatic Botany* **64**:185-208.

Coops, H. and van der Velde, G. (1995). Seed dispersal, germination and seedling growth of six helophyte species in relation to water level zonation. *Freshwater Biology* **34**:13-20.

Frankenberg, J. (1997). *Guidelines for growing Phragmites for erosion control*. CRC-Freshwater Ecology and MDFRC, Albury, NSW.

Frankenberg, J. and Tilleard, J. (1991). Protecting riverbanks from erosion. *Australian Planner* **June**: 107-110.

Haslam, S.M. (1970). The performance of *Phragmites communis* Trin. in relation to water supply. *Annals Botany* **34**:867-877.

Haslam, S.M. (1972). *Phragmites communis* Trin. Biological Flora of the British Isles. *Journal of Ecology* **60**:585-610.

Hocking, P. J. (1989a). Seasonal dynamics of production and nutrient accumulation and cycling by *Phragmites australis* (Cav) Trin. ex Steudel in a nutrient-enriched swamp in inland Australia. I. Whole plants. *Aust. J. Mar. Freshwater Res*. **40**:421-44.

Hocking, P. J. (1989b). Seasonal dynamics of production and nutrient accumulation and cycling by *Phragmites australis* (Cav) Trin. ex Steudel in a nutrient-enriched swamp in inland Australia. II. Individual shoots. *Aust. J. Mar. Freshwater Res*. **40**:445-64

Ostendorp, W. (1991). Damage by episodic flooding to *Phragmites* reeds in a pre-alpine lake: proposal of a model. *Oecologia* **86**:119-124.

Rea, N. (1996). *Reed decline and water levels*. In: R. Brandle, H. Cizkova and J. Pokorny (eds.) “Adaptation Strategies in Wetland Plants: links between ecology and physiology”. Special Features in Vegetation Science 10. Opulus Press.

Roberts, J. (2000). Changes in the distribution of *Phragmites australis* in eastern Australia: a habitat approach. *Folia Geobotanica*.

Weisner, S.E.B. and Strand, J.A. (1996). *Rhizome architecture in Phragmites*. In: R. Brandle, H. Cizkova and J. Pokorny (eds.) “Adaptation strategies in wetland plants: links between ecology and physiology”. Opulus Press, Upsala.

Weisner, S.E.B., Graneli, W. and Ekstam, B. (1993). Influence of submergence on growth of seedlings of *Scirpus lacustris* and *Phragmites australis*. *Freshwater Biology* **29**:371-375.

Canegrass

Eragrostis australasica

Several tussock grasses with similar morphology and similar habitats are known as canegrass in the Murray-Darling Basin. Only one of these, *Eragrostis australasica*, has a wide distribution and is a wetland dominant.

Eragrostis australasica is twiggy tussock grass (eg Pickard and Norris 1994). It can form dense mono-specific stands, with thick tussocks up to 2 metres tall; equally commonly, it is a spindly few-stemmed grass.

Its pale colour is due in part to a protective waxy covering on the stem. When flooded, these grasslands develop an understorey of aquatic herbs and forbs such as sedges *Eleocharis* spp., Nardoo *Marsilea drummondii* and charophytes.

The ecological equivalent of Canegrass in northern-central Victoria is *Eragrostis foecunda*. These grasslands are now recognised as breeding habitat for brolgas, and fire is used as a management tool to create an appropriate structural mosaic (Keith Ward, pers. comm. 2000). A rare aquatic plant, *Nymphoides spinulosperma*, grows in shallow (to 75 cm) water resulting from seasonal flooding of these Canegrass grasslands (Aston 1997).

Habitat

It forms extensive tussock grasslands on flood-out areas and claypans with massive non-cracking clay on drier floodplains in northern and western parts of the Basin, such as on the Paroo River system and Kulkyne Creek (King *et al.* 1995), on playas (Beadle 1981) and typically as deflation-lake vegetation in the south-west. Soils are heavy clays, sometimes slightly saline, and mostly very low permeability where flood or rain water tends to pond for several months, gradually depleting through evaporation. Canegrass is also common in modified habitats such as road-side 'table drains' on parts of the riverine plains in southern parts of the Basin.

Studies

There have been no studies of Canegrass ecology, so information is limited to few observations and mapping projects.

Maintenance

Canegrass is drought and flood tolerant. Despite this hardiness, it will die if its water regime is altered, for example by being starved of surface flows by construction of low level features such as culverts, roads or levee banks, or or by being flooded for long periods or continuously, for example by flow diversion, ponding or water dumping.

Canegrass swamps on the Mirrool Creek floodplain, west of Griffith, NSW died without regenerating after being inundated for 18 months (Roberts, pers. obs.). In north-western floodplains, Canegrass grows in depressions receiving frequent (every 1-2 years) local run-off, lasting 1-6 months (Goodrick 1984), and in areas with erratic flooding (Surrey Jacobs pers. comm. 2000).

Regeneration

The occurrence of Canegrass in roadside drains shows it can disperse and establish fairly readily in shallow depressions but other circumstances for this are not known. Experimental trials show it re-grows readily from watered canes; however, this type of regeneration is unlikely to be of major ecological significance.

REFERENCES

Aston, H.I. (1997). *Nymphoides spinulosperma* (Menyanthaceae): a new species from south-eastern Australia. *Muelleria* **10**:21-25.

Beadle, N.C.W. (1981). *The Vegetation of Australia.* Cambridge University Press, Cambridge.

Goodrick, G.N. (1984). *Wetlands of north-western New South Wales*. National Parks and Wildlife Service. Occasional Paper No. 6. July 1984.

King, A.M. Green, D.L. and Brady, A.T. (1995). *Wetlands of the Paroo River and Cuttaburra Creek.* Environmental Studies Unit, Department of Land and Water Conservation, Technical Services Division. TS 95.132. July 1995.

Pickard, J. and Norris, E.H. (1994). The natural vegetation of north-western New South Wales: notes to accompany the 1:1000,000 vegetation map sheet. *Cunninghamia* **3**:423-464.

Summary Sheet: Grasses

Maintenance of Established Grasses

Spiny Mudgrass *Pseudoraphis spinescens*:

Duration of 3-5 months minimum starting from mid-winter in order to achieve full stem extension; duration of 7 months optimum until after mid-summer to eliminate competition from milfoil; more than 10 months likely to be detrimental. Depth minimum of 0.5 m needed to eliminate competition from River Red Gum seedlings, tolerant of depths to 2 metres. Summer floods may be shorter.

Water Couch *Paspalum distichum*

Requires moist - wet soil conditions for most (75%) of year especially during growing season of spring-summer; floods may be either shallow (5-15 cm) continuous and lasting several (4-6) months or be pulsed, 2-3 times during year. Can recover from dry period of 1-2-3 years but repeated dry spells likely to affect long-term vigour.

Common Reed *Phragmites australis*

Tolerates a range of water regime conditions from permanently flooded in 1-1.5 m to infrequently (1 in 20) flooded on riverbanks: requirements for extensive stands in flat areas probably narrower. No seasonal requirement has been noted but near annual (1 in 1-2) flood frequency to maintain vigour.

Canegrass *Eragrostis australasica*

Scant information suggests brief fairly shallow (5-40 cm) frequent flooding, every 2-5 years for 1-6 months, but with no indication as to whether season is important.

Eragrostis infecunda

Optimum conditions for flowering are shallow flooding (< 50 cm) for six months (range 3-9 months) in spring-summer.

Regeneration

Spiny Mudgrass *Pseudoraphis spinescens*:

Germination and establishment requirements with respect timing, duration and depth not known other than germination can occur in both moist muds and under shallow water.

Regeneration from plant fragments probably occurs but circumstances and importance of this not known.

Water Couch *Paspalum distichum*

Germination and seedling establishment requirements not known with respect to timing or duration but depth may be critical as seeds do not germinate under water.

Common Reed *Phragmites australis*

Reproduction from seed and seedling not known under field conditions

Like other emergents, can regrow from fragments, both stem and rhizome. This is useful for propagating but not readily translated into a field management option.

Canegrass *Eragrostis australasica* & *Eragrostis infecunda*

Insufficient information

SEDGES and RUSHES
Sedgelands & Rushlands

Sedgelands and rushlands are a type of vegetation where the dominant and characteristic plant is a sedge (typically species in the family Cyperaceae) or a rush (typically a *Juncus* in the family Juncaceae): trees and shrubs are generally absent or sparse, or restricted to a littoral fringe. These plant communities may be short (to 0.5 metres), medium (0.5-1 metre) or tall (>1 metre) depending on the dominant species and its vigour.

Sedges and rushes here includes Cumbungi (*Typha* spp. in the family Typhaceae), which is also an emergent macrophyte. This follows the approach of Walker and Hopkins (1990). Strictly, *Typha* is neither a sedge nor a rush, but there is no convenient word to describe the vegetation type where *Typha* is dominant. Sometimes *Typha* spp are included with grasses (eg Briggs 1981), although not a grass.

Both Cyperaceae and Juncaceae are species rich and are common in wetlands, floodplains and riparian habitats. The family Typhaceae, however has only two native species.

Terminology

There is little consistency in common or botanical usage of 'sedge' and 'rush'. They are used loosely and sometimes interchangeably which is confusing. 'Sedge' and 'rush' are used in many of the common names applied to monocots other than grasses, especially those adapted to growing in wet or temporarily wet environments. 'Rush' is sometimes used for 'jointed rushes' in Restionaceae and derived families, as well as species in Lomandraceae; 'sedge' also refers to some *Lomandra* spp.

As the focus here is on dominant and characteristic plant species of lowland river systems in the Murray-Darling Basin, the word 'rush' implies *Juncus* spp, and 'sedge' implies Cyperaceae.

Rushlands

Rushlands have a limited distribution, occurring mainly as relatively small areas in the southern parts of the Basin. Most of the rushes are not palatable to stock, so tend to persistent or even expand under grazing pressure. Some rushlands are derived; their present size being the result of removing the tree overstory, a history of high or persistent stocking, combined with specific water management.

Giant Rush *Juncus ingens*

Only one species in the Juncaceae forms extensive mono-specific stands, Giant Rush *Juncus ingens*. Tall rushlands of this species occur in the mid-Murray River Red Gum forest complexes, and as patches along other southern rivers. In some wetlands, eg Wanganella Swamps southern Riverina, *Juncus ingens* is a nesting site for colonial waterbirds, specifically ibis. In the Barmah Forest, tall rushlands of *Juncus ingens* are believed to have established during years of reduced winter-spring flooding (Chesterfield 1986); they persist in low-lying areas where there are shallow or moist conditions over the summer months (Chesterfield 1986).

Comparison of natural and current flooding patterns (Leitch 1989) suggest that *Juncus ingens* rushlands have established where river regulation has reduced flood frequency and flood duration, from an average of 8.6 to 3.6 months (Table 4 in Leitch 1989).

Juncus ingens is not found in deep water. This is consistent with having low capacity to oxygenate its rhizosphere: convective flow rates down the culm are low, and the species has very high air resistance at the culm-rhizome junction (Brix *et al.* 1992).

In northern Victoria, *Juncus ingens* occurs where flooding is in winter–spring, last for 6-11 months, but with an optimum duration of 9 months, and in depths of up to 1.5 m (Ward 1996).

Other *Juncus*

There is very little ecological knowledge of other *Juncus* species, even though they are one of the most common forms on the floodplains. Except for a few species, experience and expertise are required for identification; these exceptions are often introduced species or species with a different (eg prostrate, or jointed) growth form. Some common *Juncus* species are described in Romanowski (1998).

Juncus articulatus is an introduced species with a long-lived seed bank, at least 12 years. Although common, it seldom dominates or forms rushlands, except in wetlands where altered and variable water regime can sometimes favour it and sometimes its competitor, the grass *Glyceria australis* (Smith and Brock 1998).

Water regime: other *Juncus*

The following notes are based on field observations for north-central Victoria (Ward 1996).

Juncus pallidus: found where floods occur in winter-spring and last from 4-8 months, but with a growth optimum of 5 months, and water is generally shallow, less than 1 metre.

Sedgelands

Sedgelands occur throughout the Basin, except on driest north-west floodplains. In lowland areas, they occur typically on heavy grey clays on intermittently or seasonally-wet flood-out areas and shallow depressions. These soil-water conditions occur on wetlands terminal to tributaries of the main Murray-Darling system, and on active floodplains. Most sedgelands are small (compared with forests and woodland areas). On the Culgoa and Birrie and Narran floodplains, sedgelands cover only 12 ha, which is less than 0.01% total floodplain area (Dick 1993).

The area that is sedgelands has probably been severely reduced by water management and by stocking. On the Lower Gwydir floodplain, sedgelands presently cover over 1000 ha, but would have been even larger before dam construction and development (Bennett 1992).

It is possible that the current extent and distribution of sedgelands and sedges is underestimated. Most sedges are palatable to stock, thus stock grazing means the small and medium-tall species are inconspicuous under dry conditions.

The habitat value of sedgelands for aquatic fauna is poorly documented. In a degraded billabong near Wagga Wagga, beds of *Eleocharis sphacelata* proved to be the most important micro-habitat for an amphibian, *Limnodynastes fletcheri* (Healey *et al.* 1997).

Sedgeland species

In contrast to rushes and to Cumbungi, there are a number of Cyperaceae that form sedgelands. For descriptions of non-riverine sedgelands and sedgelands outside the Basin, see Briggs (1981) and Beadle (1981).

Short-medium tall *Eleocharis* sedgelands occur widely: *Eleocharis plana* on the Gingham watercourse, a terminal wetland (McCosker and Duggin 1993); *Eleocharis pallens* on floodplains of rivers in the semi-arid parts of the Basin, both northern and southern (Fox 1991, Dick 1993). A short-medium height mixed grassland-sedgeland occurs on gilgai soils, with sedges in the hollows; *Eleocharis acuta* with *Pseudoraphis spinescens* in the River Red Gum forests of the mid-Murray (Margules *et al.* 1990) and on the Macquarie Marshes, *Eleocharis plana* and *Juncus aridicola* mix with a variety of grass species (Paijmans 1981). Tall sedgeland of *Bolboschoenus fluviatilis* occurs in the Gwydir floodplain.

Bolboschoenus spp.

There are three significant and sometimes dominant wetland species in this genus. Ranging in height from tall to medium, they are: *Bolboschoenus fluviatilis*, *B. medianus* and *B. caldwelli*. Only one of these, *B. medianus* has been much studied (Blanch *et al*. 1999, Siebentritt and Ganf 2000).

Bolboschoenus medianus is a species with a water regime tolerance that is narrower than medium-tall emergent macrophytes, such as *Typha* spp or *Phragmites*. Its growth is optimal across a water depth range of approx 0 to 20 cm (Blanch *et al.* 1999). This species is sensitive to water stress, so does not extend far above the water line; there is some indication of increasing sensitivity to water stress with phenological stage, as in experimentally-grown plants, *B. medianus* was more sensitive to water stress in autumn than in summer (Blanch *et al*. 1999, Siebentritt and Ganf 2000).

In the littoral zone, the distribution of *B. caldwelli* overlaps with that of *B. medianus*, suggesting these should similar water regime requirements and responses. However, experimental studies show that although both species have a lower physiological limit at water depths of 60 cm (Siebentritt and Ganf 2000), the growth of *B. medianus* is generally more vigorous at depths of 0 to 40 cm and that *B. caldwelli* grows best from just above the waterline to depths of 20 cm.

The difference between these two species is evident also in their occurrence on the banks of the River Murray, South Australia. According to Blanch *et al.* (1999), *Bolboschoenus caldwelli* occurs in areas which are flooded for a total of only 43-70 days per year and always to less than 60 cm; whereas *Bolboschoenus medianus* is found where flooding occurs for a total of 80-215 days per year, to less than 60 cm depth.

Other sedges

There are several other sedge species of ecological significance. These are better known than *Juncus* species; in general, Cyperaceae species are easier to identify.

Some are important understorey species: for example, *Carex tereticaulis* and, to a lesser extent, *Carex bichenoviana* and *Carex appressa,* are typical ground cover in River Red Gum forests of the southern rivers (Chesterfield 1986), and *Eleocharis plana* is understorey in River Red Gum woodland in the Macquarie Marshes (Paijmans 1981). Other significant sedges include: *Eleocharis pallens* in Canegrass grassland in south-west of New South Wales (Scott 1992, Porteners 1993); *Eleocharis sphacelata* in seasonal or near permanent billabongs; Spiny Sedge *Cyperus gymnocaulos* fringing riverine lakes, deflation basins and channels in western and drier areas. Most of these are described and illustrated in Sainty and Jacobs (1994) or Romanowski (1998).

There are only a few physiological and ecological studies of these species and their water regime requirements or adaptations. These include:

Carex bichenoviana: effects of submergence and siltation (in prep. Bronwyn Lowe, PhD, CSU Wagga Wagga).

Eleocharis sphacelata: mechanisms and rates of rhizosphere oxygenation and internal gas flow, and models of these (Sorrell 1994, Sorrell and Boon 1994).

Eleocharis spp: a comparative study (in prep. Dorothy Bell, PhD, University of New England).

Water regime: other sedges

Knowledge of water regime tolerances and requirements for sedges are summarise here. These are based on field observations from northern Victoria (Ward 1996) and from banks of River Murray, South Australia (Blanch *et al.* 1999b), plus experimental studies as indicated.

Carex tereticaulis: tolerates flooding of 1-4 months in northern Victoria, to 10 cm in spring-summer, but optimum duration is 2 months.

Cyperus exaltatus: 135-200 days, mainly at depths less than 60 cm, along the River Murray, South Australia.

Cyperus gymnocaulos: 80-195 days, usually to less than 60 cm, beside the river in South Australia (Blanch *et al.* 1999); tolerates 2-6 months flooding in northern Victoria, very shallow less than 10 cm, but optimum flooding is 3 months in spring-summer (Ward 1996).

Eleocharis acuta: optimum duration is 8 months in northern Victoria, though the species tolerates 3-10 months flooding, and shallow depths, typically 10 cm; in spring-summer (Ward 1996); in a glasshouse experiment, grew 3-4 times better at 0 cm depth than under 15 cm (Blanch and Brock 1994).

Schoenoplectus validus: confined to permanently wet-moist sites, occurring where flooding occurs for 350-365 days per year, to depths of 20-60 cm (Blanch *et al*. 1999).

Typha spp.

Stands of Cumbungi *Typha* occur on only a few floodplains - the Macquarie Marshes, the Great Cumbung Swamp – but cover many individual wetlands, especially those with a permanent water regime, such as in the mid-Murray region. Because field identification is usually to level of genus only, even though the two species are reasonably distinct, it is not known which of the two is more important. Cumbungi is often considered indicative of degradation. Both species disperse widely and establish a large canopy readily, so can out-compete other emergent macrophytes.

Despite the number and diversity of sedges and rushes, only Cumbungi has been studied extensively enough to be profiled.

REFERENCES

Beadle, N.C.W. (1981). *The vegetation of Australia*. Cambridge University Press, Cambridge.

Bennett, M. (1992). *Water management options for Gwydir valley wetlands*. Department of Water Resources, Technical Services Division.

Blanch, S.J. and Brock, M.A. (1994). Effects of grazing and depth on two wetland plant species. *Aust. J. Marine Freshw Research* **45**:1387-94.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999). Growth and resource allocation in response to flooding in the emergent sedge *Bolboschoenus medianus*. *Aquatic Botany* **63**:145-160.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999b). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Briggs, S.V. (1981). Freshwater Wetlands. In: R.H.Groves (ed.) “Australian Vegetation”. First edition. Cambridge University Press, Cambridge.

Brix, H., Sorrell, B.K. and Orr, P.Y. (1992). Internal pressurization and convective gas flow in some freshwater emergents. *Limnology and Oceanography* **37**:1420-1433.

Chesterfield, E.A. (1986). Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Australian Forestry* **49**:4-15.

Dick, R. (1993). *The vegetation of the Wombeira Land system on the floodplains of the Culgoa, Birria and Narran Rivers in NSW-November 1990.* Occasional Paper 13. National Parks and Wildlife Service (NSW), Hurstville, NSW.

Fox, M.D. (1991). The natural vegetation of the Ana Branch - Mildura 1:250 000 sheet (New South Wales). *Cunninghamia* **2**:443-494.

Healey, M. Thompson, D. and Robertson, A. (1997). Amphibian communities associated with billabong habitats on the Murrumbidgee floodplain, Australia. *Australian Journal of Ecology* **22**:270-278.

Leitch, C. (1989). *Towards a strategy for managing the flooding of Barmah forest*. Department of Conservation, Forests and Lands Benalla, Victoria. 46 pp.

McCosker, R. O. and Duggin, J.A. (1993). *Gingham Watercourse Management Plan: Final Report.* University of New England, Armidale 2351. 45 pp.

Margules and Partners Pty Ltd. (1990). *River Murray vegetation Study*. Prepared for the Murray-Darling Basin Commission by Margules and Partners Pty Ltd, P and J Smith Ecological Consultants, Department of Conservation Forests and Lands Victoria. Murray Darling Basin Commission, Canberra. January 1990.

Paijmans, K. (1981). *The Macquarie Marshes of Inland northern New South Wales, Australia*. Division of Land Use Research Technical Paper No 41. CSIRO, Australia.

Porteners, M. F. (1993). The natural vegetation of the Hay Plain: Booligal-Hay and Deniliquin-Bendigo 1:250,000 maps. *Cunninghamia* **3**:1-122.

Romanowski, N. (1998). *Aquatic and Wetland Plants: a field guide for non-tropical Australia*. University of New South Wales, Press, Sydney.

Sainty, G. and Jacobs, S. (1994) *Waterplants in Australia: A field guide*. Third edition. Sainty and Associates, Sydney.

Scott, J.A. (1992). The natural vegetation of the Balranald - Swan Hill area. *Cunninghamia* **2**:597-602.

Siebentritt, M.A. and Ganf, G.A. (2000). Influence of abiotic and biotic factors on two co-occurring species of *Bolboschoenus*. *Marine Freshwater Research* **51**:73-80.

Smith, R.G.B. and Brock, M.A. (1998). Germination potential, growth patterns and reproductive effort of *Juncus articulatus* and *Glyceria australis* in temporary shallow wetlands in Australia. *Wetlands Ecology and Management* **5**:203-214.

Sorrell, B.K. (1994). Airspace structure and mathematical modelling of oxygen diffusion, aeration and anoxia in *Eleocharis sphacelata* R.Br. roots. *Aust. J. Mar. Freshwater Res*. **45**:1529-41.

Sorrell, B. K. and Boon, P.I. (1994). Convective gas flow in *Eleocharis sphacelata* R. Br.:

methane transport and release from wetlands. *Aquatic Botany* **47**:197-212.

Walker, J. and Hopkins, M.S. (1990). *Vegetation.* In: “Australian Soil and Land Survey: Field Handbook.” R.C. McDonald, R.F. Isbell, J.G. Speight, J. Walker and M.S. Hopkins (eds). Second edition. Inkata Press, Melbourne.

Ward, K. (1996). Flood requirements of vegetation for the rehabilitation of Lake Mokoan. Department of Natural Resources and Environment. Unpublished draft report.

Cumbungi

Typha orientalis & Typha domingensis

Cumbungi, *Typha* sp., is an emergent macrophyte, which looks like a large grass, with leaves up to 3-4 metres long in vigorous plants. It grows in moist conditions and in water up to 2 metres deep. Its robust rhizome (underground stem) is the key to its survival and vigour, as it is the starch-rich rhizome that supplies growing shoots in spring and allows early canopy development. The rhizome apex has two rows of dormant buds. These are activated when the shoot is lost or damaged, for example by herbivory or fire.

Rhizome and roots are oxygenated by air moving down the shoots (eg White and Ganf 1998), and it is this that determines its depth tolerance. Comparative studies of eight emergent macrophyte has shown that *Typha,* like *Phragmites* and *Eleocharis sphacelata,* is well-adapted to ventilate its root and rhizome system through pressurised ventilation and low resistance to airflow (Brix *et al.* 1992).

The common name used here, cumbungi, is only one of several used around Australia.

Growth

Cumbungi is one of the most productive emergent macrophytes, growing even more vigorously in nutrient-rich conditions (Froend and McComb 1994). It forms tall (2-4 m) stands so dense that other plants are excluded. Large stands occur in some terminal wetlands such as the Macquarie Marshes and the Great Cumbung Swamp, and in many lake-like wetlands such as Lake Boga, northern Victoria.

Stands of *Typha* can establish rapidly under appropriate water regime or if the water regime changes and becomes suitable, such as ponded water, summer releases or major flooding. Such stands last as long as conditions remain wet enough, or not too deep (ie < 2 m). If these conditions change and are sustained, then the stand loses vigour, ceases to expand and eventually dies away. Such dramatic changes in abundance are known for parts of the Gwydir floodplain, the Mirrool Creek floodplain and for Barrenbox Swamp.

Species

Cumbungi refers to both Australian species, the broad-leafed *T. orientalis* and the narrow-leafed *T. domingensis.* Both species are found in the Basin. A third species, the introduced *T. latifolia* with its distinctive near-black inflorescence, is presently found only in the south-eastern part of the Basin, mainly in the Shepparton region, but is possibly expanding.

The two Australian species can be readily identified in the field, based on leaf and spike characteristics.

Invasive character

Cumbungi is an invasive species, growing vigorously in response to disturbance, particularly altered water regime, silt deposits and/or increased nutrients. It has potential as an indicator of environmental change, and has been used as such on the Mirrool Creek floodplain (Roberts and Wylks 1992). In WA, *T. orientalis* is an environmental weed as it has displaced native sedges from some wetlands on the Swan Coastal Plain (Froend and McComb 1994). In irrigation areas, *Typha* is a problem because it can completely cover farm dams and rice fields, and clog channels and drains.

Australian studies

The ecology and biology of *Typha* in Australia is better known than many other wetland species, and early knowledge was summarised by Finlayson *et al*. (1983). Ecological studies since then include: production (Roberts and Ganf 1986), the interactive role of nutrients and water regime in WA wetlands (Froend and McComb 1994), salinity tolerance (Hocking 1981), rhizome ventilation (Brix *et al.* 1992, White and Ganf 1998); regeneration niche (Nicol and Ganf 2000).

Typha is an important habitat for cryptic waterbirds, such as crakes and rails, and for reed-warblers, and a breeding habitat for musk-duck and blue-billed ducks (Braithwaite *et al*. 1969, Frith 1959). Cumbungi swamps, often the product of near permanent water and agricultural drainage, are valuable drought refuges for water birds. *Typha* was a useful plant for Aborigines: rhizomes and young shoots were used as food, and leaves were a source of net fibre.

Maintenance

Leaves grow slowly through winter, then very rapidly in spring and early summer. After mid-summer, growth is below-ground as carbohydrate storage is increased in the rhizome while shoots senesce. New shoots emerge in autumn-winter. These grow slowly if it is warm enough, as it is in most lowland areas of the Basin. Flowering is in spring-summer.

Typha grows where the water regime ranges from permanently wet to seasonally or periodically dry. Field observations show it is strongly favoured by a water regime that is wet in spring-summer, and/or by a water regime that is stable, at least during the early growing season. Relatively stable water levels appear to favour *Typha* over other emergent macrophytes whilst fluctuations favour other species such as *Phragmites*. The species is limited by extremes of both wet (as water depth) and dry conditions. If water depth remains at 2 metres or more, the roots and rhizome become oxygen-starved, so lose vigour, and eventually die.

Typha has a high water requirement and does not survive long in continuously dry conditions above the waterline. However, it can tolerate dry conditions for short periods (3-4 months in summer-autumn) once the growing season is over, without loss of vigour. The rhizome can survive dry conditions for even longer, possibly a few years, if protected from desiccation by being deep (0.5 m) within heavy clay.

On the banks of the River Murray, South Australia, *Typha domingensis* is found in permanently flooded or moist sites; it is found where flooding occurs for 360-365 days per year, mainly in water depths of 20-60 cm (Blanch *et al.* 1999).

In northern Victoria, Ward (1996) records that *Typha orientalis* is found where flooding last for 9-12 months per year, and that the optimum conditions are 11 months duration, and depth of less than 2 metres.

Regeneration

Typha flowers in spring-summer. Seed production is high, and the few hundred thousand seeds on each inflorescence are wind dispersed in late summer-early autumn.

To germinate, Cumbungi seeds require light (zero germination in the dark), moisture and temperatures of at least 10^{o}C but preferably greater than 16^{o}C (Roberts 1987). Seeds of *T. orientalis* germinate and establish on wet mud or under shallow (5 cm) water (Froend and McComb 1994). Small seed mass, 24-35 micrograms for *T. domingensis* and 35-49 micrograms for *T.orientalis*, means that although seeds can germinate under water, seedling establishment is dependent on leaves reaching air to start photosynthesis (Nicol and Ganf 2000).

An appropriate water depth and lack of water stress are needed for seedlings. By the end of a 14-week experiment, *T. domingensis* seedlings that germinated on wet muds had reached a dry weight of 474 g, whereas seedlings under a constant depth of 30 cm reached only 10 g, and most in fast draw-down and rapidly drying conditions did not even reach 1 g (Nicols and Ganf 2000). Because growth is so rapid, especially under nutrient-rich and warm conditions, seedlings can reach a metre in height in only a few months, and already have a rhizome.

REFERENCES

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Braithwaite, L.W. and Frith, H.J. (1969). Waterfowl in an inland swamp in New South Wales. I. Habitat. *CSIRO Wildlife Research* **14**:1-16.

Brix, H., Sorrell, B.K. and Orr, P.T. (1992). Internal pressurization and convective gas flow in some emergent freshwater macrophytes. *Limnology and Oceanography* **37(7):**1420-1435.

Finlayson, C.M., Roberts, J., Chick, A.J. and Sale, P.J.M. (1983). The biology of Australian Weeds. II. *Typha domingensis* Pers. and *Typha orientalis* Presl. *J. Institute Agric. Sci*. **49**:3-11.

Frith, H.J. (1959). The ecology of wild ducks in inland New South Wales. I. Waterfowl habitats. *CSIRO Wildlife Res* **4**:97-107.

Froend, R.L. and McComb, A.J. (1994). Distribution, productivity and reproductive phenology of emergent macrophytes in relation to water regimes at wetlands of south-western Australia. *Aust. J. Mar. Freshwater Res.* **45**:1491-1508

Hocking, P.J. (1981). Response of *Typha domingensis* to salinity and high levels of manganese in the rooting medium. *Aust. J. Mar. Freshwater Res*. **32**:907-919.

Nicol, J.M. and Ganf, G.G. (2000). Water regimes, seedling recruitment and establishment in three wetland plant species. *Mar. Freshwater Res*. **51**:305-310.

Roberts, J. (1987). *The autecology of Typha spp. in south-eastern Australia*. Unpub PhD, Department of Botany, University of Adelaide.

Roberts, J. and Ganf, G. (1986). Annual production of *Typha orientalis* Presl. In inland Australia. *Aust. J. Mar Freshwaer. Res*. **37**:659-668.

Roberts, J. and Wylks, H. (1992). *Wetland Vegetation of the Floodway: Monitoring program.* CSIRO Division of Water Resources, Griffith. Consultancy Report 92/06.

Ward, K.F. (1996). Flood requirements of vegetation for the rehabilitation of Lake Mokoan. Department of Natural Resources and Environment. Draft report.

White, S.D. and Ganf. G.G. (1998). The influence of convective flow on rhizome length in *Typha domingensis* over a water depth gradient. *Aquatic Botany* **62**: 57-70

Summary Sheet: Sedges & Rushes

Maintenance of Established Sedges and Rushes

Club Rushes *Bolboschoenus medianus* & *Bolboschoenus caldwelli*

For *Bolboschoenus medianus*, a flood frequency of at least once a year, relatively stable water levels; optimal depths are 0-20 cm for *B. caldwelli* and 0-40 cm for *B.medianus*. Flood duration should be 20-60% of time, during the growing season. Sensitive to rates of recession. Flood depth should not exceed 50-75% of shoot height; recession, if needed, must be slow, 2 cm day^{-1}. Water levels should not be more than 0.2 m below surface for *B. caldwelli* and 0.5 for *B. medianus*.

Cumbungi *Typha orientalis* & *Typha domingensis*

Flood near annually (1 in 1-2): rhizome can survive without flooding 1-2 years, if well-established. Duration ideally 7-9 months but 6-12 months also; if short duration, then should cover winter-spring-early summer, Depth range variable, from 5 cm to 1.5 m. Flooding can be pulsed, providing ground remains saturated between pulses; inter-flood interval in mid-summer of 1-2 weeks.

Giant Rush *Juncus ingens*

Shallow or water-logged conditions during warmer months, and current distribution suggests a mean flood duration of 4 months, frequency nearly every year.

Eleocharis spp. (E. acuta, E. pallens, E. plana, E. sphacelata)

Insufficient information

Regeneration

Club Rushes *Bolboschoenus medianus* & *Bolboschoenus caldwelli*:

Insufficient information

Cumbungi *Typha orientalis* & *Typha domingensis*

Shallow water or saturated muds (0-5 cm) for germination, deeper water (5-10-15 cm) for seedling growth, also continuously moist conditions for several months until seedling established, shorter (3 months) in warm (summer) and longer (6 months) over winter.

No species differences known

Giant Rush *Juncus ingens*

Seedlings are thought to be intolerant of being submersed; regeneration is unlikely in areas that are flooded.

Eleocharis spp. (E. acuta, E. pallens, E. plana, E. sphacelata)

Insufficient information

SUBMERGED MACROPHYTES
Benthic Herblands

Submerged macrophytes grow under water, in lentic and lotic aquatic systems. They range in size from a few centimetres to 2-3 metres tall. Submerged macrophytes may be annuals or perennials. Stoloniferous and rhizomatous perennials tend to form mono-specific patches. In flowing water these patches can be sparse but in permanently-flooded wetlands, the patches tend to expand to give continuous cover.

The importance of submerged macrophytes in wetland and riverine processes and as significant habitat is well established overseas (eg Jeppeson *et al.* 1997). Scientific thinking in Europe recognises that shallow lakes exist in different ecological stable states, of which one is dominance by macrophytes. Research into which factors cause macrophyte dominated systems to become phytoplankton-dominated systems usually link the switch to eutrophication, or to lack of water clarity due to excessive phytoplankton.

The light energy and carbon dioxide needed for photosynthesis must be obtained by leaves that are submerged, rather than in air. Thus growth of these aquatic plants is more sensitive to gross changes in water quality (notably pH, transparency and spectral composition) than emergent macrophytes. Pulses of turbid water can result in pulsed growth and decline, and fluctuating populations (eg Johnstone and Robinson 1987).

There is no simple rule as to whether submerged macrophytes obtain their nutrients from the water column or from the sediments (ie roots) or both. Instead there are differences between species and between circumstance, ie whether sediment and/or water is enriched.

Habit

Submerged leaves are usually thin, only a few cells thick, and lack a protective outer layer: consequently, they dry out rapidly if exposed by falling water levels, and die. Stems and leaves are non-rigid, and move with currents; thus submerged plants are not as bulky as emergent macrophytes.

Some submerged macrophytes have two types of leaves, a condition known as heterophyllly: submerged leaves, and a few aerial leaves. The aerial leaves tend to be thicker, have a better cuticle (protective layer) and are less likely to be dissected.

Most submerged macrophytes have roots that anchor them to the sediment. A few species float within the water column, for example *Lemna trisulca* and Hornwort *Ceratophyllum demersum*. Short mat-forming plants such as *Elatine gratioloides*, *Glossostigma* spp. grow in very shallow water and are sometimes counted as submerged macrophytes but are closer to amphibious plants. Unlike larger submerged macrophytes, they grow at and even above the waterline in cool or moist areas or in wave-flushed littoral zone in hot dry climates where they can tolerate brief periods of exposure.

There are two types of leaf arrangement. Basal leaves grow from an apex in the sediment and have no stem in the water column; basal leaves are either strap-like, as in *Vallisneria*, or form flat rosettes. Cauline leaves grow from a central stem which grows towards the water surface, and vary in shape; some are flat, as in Curly Pondweed *Potamogeton crispus*; some are thin cylinders, as in *Lepilaena* spp and *Ruppia* spp., and some are highly dissected, as in many milfoils for example Red Milfoil *Myriophyllum verrucosum* and the bladderworts, *Utricularia* spp. The habitat value of submerged plants changes with plant density and complexity of leaf form.

Nuisance & noxious species

Dense growths of submerged macrophytes can become a nuisance or even a hazard in lakes or storages that are used for recreation or hydro-electric power generation. Excessive growths of submerged macrophytes have occurred in lakes and wetlands within the Murray-Darling Basin but problematic growths are less common than previously.

Submerged macrophytes are considered a nuisance in irrigation channels where they reduce hydraulic capacity; small mat-forming species and some charophytes occur in rice fields, but rarely reach nuisance levels.

Introduced submerged species such as *Elodea canadensis*, *Lagarosiphon major* and *Egeria densa,* some of which occur in urban areas and irrigation channels are internationally recognised as serious or noxious weeds; these are rarely recorded in lowland river systems.

Australian studies

Physiological studies are few, eg *Myriophyllum salsugineum* (Orr *et al.* 1988), *Vallisneria americana* (Blanch *et al.* 1998). Growth ecology in relation to water regime or water quality has been studied for *Myriophyllum variifolium* (Brock 1991, Brock and Casanova 1991), charophytes (eg Casanova 1994, Casanova and Brock 1999), and Ribbonweed *Vallisneria americana* (Blanch *et al.* 1998). Seasonal and post-inundation changes in abundance have been documented in natural wetlands with periodic flooding (Briggs and Maher 1985). Longer-term shifts in species composition and relative abundance under permanent water regime have been documented in a constructed lake (Royle and King 1991).

Paleo-ecological studies (Ogden, in press) and anecdotal information (Roberts 1999) indicate at least two periods of catastrophic decline in submerged plant abundance in the Murray-Darling Basin since European settlement began.

The significance of submerged macrophytes is beginning to be studied and appreciated. Research into the growth and nutrient dynamics and the interplay of phytoplankton and *Vallisneria* are under way (Paul Boon, pers. comm. 2000). The importance of submerged macrophytes for water birds, both as a food source and as nesting material, is well-established in water bird ecology: recent research suggests that submerged macrophytes of brackish and saline systems are particularly important (eg Kingsford and Porter 1994). The different leaf shapes of different species make a distinctive habitat structure which is reflected in abundance patterns and distribution patterns of micro-fauna in billabongs (Shiel 1976, Ogden, in prep.).

Regeneration

Many submerged macrophytes can grow from plant fragments. However, stem fragments are easily desiccated so this is not a reliable means of regeneration in wetlands which dry out periodically or which are hydrologically isolated.

Although the plant grows underwater, reproduction is usually completed above water, either in the air or at the water surface. In some species, notably *Vallisneria*, flowers which have developed below the surface extend upwards by uncoiling their corkscrew-like peduncles. Others, such as the milfoils, hold their flowers a few centimetres above the water. Most submerged macrophytes have inconspicuous flowers with no or very reduced petals.

Species

Species which are unusual, rare or possibly contracting in range include carnivorous species such as *Utricularia* spp., and others such as *Zannichellia palustris*, *Montia fontana*, and Hornwort *Ceratophyllum demersum*.

Submerged macrophytes in the Murray-Darling Basin are a mixture of native and cosmopolitan species. Examples of native species are the milfoils *Myriophyllum* spp, also Blunt Pondweed *Potamogeton ochreatus, Hydrilla verticillata* and Waternymph *Najas tenuifolia*. Cosmopolitan species and species with distributions that extend beyond Australia include several pondweeds such as Curly Pondweed *Potamogeton crispus*, Sago Pondweed *Potamogeton pectinatus,* also Hornwort *Ceratophyllum demersum*, and *Lemna trisulca*.

Benthic herblands

Species forming benthic herblands in lowland riverine systems of the Murray-Darling Basin include Curly Pondweed *Potamogeton crispus*, Ribbonweed *Vallisneria americana*, several charophytes, *Myriophyllum salsugineum* and *Myriophyllum fascicularis*, and Red Milfoil *Myriophyllum verrucosum* which is the most widespread milfoil in Australia (Orchard 1985).

The extent, diversity, and species composition of benthic herblands in the Murray-Darling Basin is virtually unknown.

REFERENCES

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1998). Growth and recruitment in *Vallisneria americana* as related to average irradiance in the water column. *Aquatic Botany* **61**:1810-205.

Briggs, S.V. and Maher, M.T. (1985). Limnological studies of waterfowl habitat in south-western New South Wales. II. Aquatic macrophyte productivity. *Aust J. Mar. Freshw. Res*. **36**:707-15.

Brock, M.A. (1991). Mechanisms for maintaining persistent populations of *Myriophyllum variifolium* in a fluctuating Australian shallow lake. *Aquatic Botany* **39**:211-219

Brock, M.A. and Casanova, M.T. (1991). Vegetative variation of *Myriophyllum variifolium* in permanent and temporary wetlands. *Aust. J. Bot*. **39**:487-96

Casanova, M.T. (1994). Vegetative and reproductive responses of Charophytes to water-level fluctuations in permanent and temporary wetlands in Australia. *Aust J. Mar. Freshw Res*. **45**: 1409-19.

Casanova, M.T. and Brock M.A. (1999). Life histories of charophytes from permanent and temporary wetlands in eastern Australia. *Australian Journal of Botany* **47:**383-397.

Jacobs, S.W.L. and Wilson, K.L. (1996). A biogeographical analysis of the freshwater plants of Australasia. *Australian Systematic Botany* **9**:169-183.

Jeppeson. E., Sondergaard, M., Sondergaard, M., Christoffersen, K. (eds). (1997). *The structuring role of submerged macrophytes in lakes.* Ecological Studies Volume 131. Springer. New York. pp423.

Johnstone, I.M. and Robinson, P.W. (1987). Light level variation in Lake Tutira after transient sediment inflow and its effect on the submersed macrophytes. *New Zealand Journal of Marine and Freshwater Research* **21**:47-53.

Kingsford, R.T. and Porter, J.L. (1994). Waterbirds on an adjacent freshwater lake and salt lake in arid Australia. *Biological Conservation* **69**:219-228.

Ogden . R. (in press.) Modern and historic variation in aquatic macrophyte coverage of billabongs associated with catchment development. *Regulated Rivers: Research and Management*.

Orchard, A.E. (1985). *Myriophyllum* (Haloragaceae) in Australasia. II. The Australian species. *Brunonia* **8**:173-291.

Orr, P.T., Pokorny, J., Denny, P. and Sale, P.J.M. (1988). Photosynthetic response of *Myriophyllum salsugineum* A.E. Orchard to photon irradiance, temperature and external free CO_2. *Aquatic Botany* **30**: 363-378.

Roberts, J. (1999). *Taking the pulse*. In: Kingsford, R.T. (ed.) "A free-flowing river: the ecology of the Paroo River". NSW National Parks and Wildlife Service, Sydney. National Parks and Wildife, Sydney.

Royle, R.N. and King, R.J. (1991). Aquatic macrophytes in Lake Liddell, New South Wales: biomass, nitrogen and phosphorus status, and changing distribution from 1981 to 1987. *Aquatic Botany* **41**:281-298.

Shiel, R.J. (1976). Associations of Entomostraca with weedbed habitats in a billabong of the Goulburn River, Victoria. *Austr J. Mar. Freshw. Res*. **27**:533-549.

Charophytes

Charophytes, in the family Characeae, are a "very special group of green plants, not really true algae because they have complex reproductive structures, but very different from the flowering plants" (Feist and Soulié-Märsche, 1999). The 'stem' is really a chain of cells. If the chain is single cells, end to end, the stem is technically described as 'ecorticate'; if the central chain is surrounded by smaller cells or cortex, giving the plant a sculpted appearance, the plant is 'corticate'. Charophytes have no specialised outer cells or protective coat against water loss, hence all charophytes are extremely vulnerable to desiccation.

Lack of relevant studies and difficulties in species-level identification mean that their distribution, diversity and species richness are not well known.

Species and Taxonomy

Worldwide there are about 250 species. The number of species in Australia is not known, but are predominantly in four genera, *Chara*, *Nitella*, *Lamprothamnium* and *Tolypella.* Although a key to Australian species was prepared by Wood (1972), this work is now considered out of date, and a new study is underway.

Although species distributions have not been well surveyed it is evident that the Australian flora is a mix of cosmopolitan and endemic species. For example, a survey of lakes of varying fresh-saline water in a volcanic region of south-eastern Australia recorded 12 species; two were cosmopolitan and seven were Australian endemics, mainly in the genus *Nitella* (Garcia 1999).

Despite the general lack of knowledge of species distributions, one species *Lychnothamnus barbatus*, is known to be rare, and is listed as an Endangered Species (McCourt *et al*. 1999). Another species, *Nitella partita*, has been rediscovered in the Paroo system, after not being sighted for decades (John Porter, pers. comm. 2000).

Charophytes are reliably identified to species using microscopes to recognise characteristics such as whether the central axis is corticate or ecorticate, the degree of branching, number of cells subtending, and by ornamention on the oogonia, which are the equivalent of seeds, and are on the branchlets.

Field guides for identification to level of genus and of more common species include Romanowski (1998), Sainty and Jacobs (1994) and Entwisle *et al.* (1997). The Australian Journal of Botany has recently published an issue entirely dedicated to the biology of charophytes (Farrer 1999).

Habitat

Charophytes look like small submerged macrophytes, and occupy a similar habitat, growing completely submerged, attached to the bottom of permanent or ephemeral wetlands or flowing creeks. They may form dense and conspicuous growths over extensive areas.

Charophytes occur in most aquatic habitats, both lentic and lotic. They also occur in modified and constructed aquatic systems such as farm dams, rice fields, evaporation basins (eg Roberts 1995). Some idea of species richness can be gained from the following examples: four species were found growing in 10 out of 65 farm dams surveyed in central-western New South Wales (Casanova and Brock 1999b) but six species germinated from sediments from 17 of these dams (Casanova and Brock 1999b); six species have been recorded from Lake Nocoleche in the north-west (John Porter, pers. comm 2000).

Charophytes are a diverse group, and occur as persistent beds in permanent lakes or as pioneer benthic vegetation in recently-flooded wetlands (Casanova and Brock 1999a).

Water quality is important for all charophytes, and most occur in alkaline rather than acidic water. Species differ in their tolerance of salinity and in their requirement for calcium ions (Garcia 1999). Most Charophytes occur in fresh to brackish water: only one, *Lamprothamnium macropogon* (recorded as *L. papulosum* in many studies) occurs at salinities greater than 5.0 g L^{-1} (Garcia 1999); some *Nitella* spp. occur in bore drains supplied by highly alkaline artesian water > 5 mg L^{-1}

TDS but low salinity (John Porter pers. comm. 2000).

Most Charophytes cannot grow in water that is permanently very turbid, but some can photosynthesis at low light intensities, or can survive periods of turbid water. Such species are found in farm dams (Casanova and Brock 1999b). The discovery of viable charophyte beds, *Nitella* spp., growing under water that is shallow (to 15 cm) but with a high sediment content (to 1000 FTU) in ephemeral claypans of the Paroo system shows there are a few species well adapted to very turbid conditions (John Porter, pers. comm. 2000).

For species adapted to clear water, turbid water phases or inflows which temporarily reduce light penetration have an adverse effect on growth and hence on abundance (eg Schwarz *et al*. 1999). Plants have been recorded at depths of up to 27 m in clear-water lakes but more commonly grow in shallow waters from a few to 1 or 2 metres deep.

Appearance

Charophytes can be distinguished from small submerged macrophytes such as milfoils by their fine appearance, branching habit, shiny green and translucent appearance, their reproductive organs (anteridia and oogonia) which frequently are orange, sometimes black. Each plant is normally 10-30 cm high and consists of a central stem bearing whorls of lateral branchlets arising from nodes at more or less regular intervals along its length (Aston, 1973). The plant body is attached to the substratum by means of tiny delicate root-like structures “rhizoids” which are susceptible to disturbance and bioturbation (eg Roberts *et al*. 1995).

In some species, ion uptake and exchange processes across the cell wall result in external deposits of lime, making them brittle to touch, hence the common name ‘stonewort’. A few species have a distinctive smell, in *Nitella* due a mucous, but also in ecorticate *Chara*; this smell is probably the reason for the common name of ‘musk grass’.

Australian studies

The ecology of charophytes in Australia is only beginning to be known. Nearly all studies on the ecology and life histories of charophytes in Australia have been undertaken by Casanova (1994, 1996), Casanova and Brock (1990, 1996, 1999a), and Brock (1985), largely – but not exclusively – based on small wetlands in New England on the Northern Tablelands, also farm dams in central-wet NSW (Casanova and Brock 1999b).

Some charophytes. and in particular their bulbils and oogonia, and most notably *Lamprothamnium* sp, are a significant food source for waterfowl (Delroy 1974).

Life history

Charophytes may be annuals or perennials. They are capable of both vegetative regeneration, from bulbils, as well as sexual regeneration, from oospores. Nearly all studies have been on oospores, and little is known about bulbils.

Based on experimentation and field observations over several years, three types of life histories can be recognised for charophytes (Casanova and Brock 1999a): monoecious annuals, dioecious annuals, and dioecious perennials. A fourth type, monoecious perennial occurs but is not sufficiently well-known to be described generically.

Characteristics of each of these, in relation to seasonal and water regime responses, shoot life-span, and germination requirements, are described and presented graphically in Casanova and Brock (1999a).

Maintenance

Charophytes are dependent on being flooded in order to grow and to reproduce. Being relatively short, they can grow and survive in water that is relatively shallow (eg 5-50 cm) provided shallowness is not the result of drawdown and conductivity increasing through evaporation.

Charophytes are generally tolerant of changes in water level, provided the changes do not expose them, as this will result in rapid desiccation and death. In some species, eg *Chara australis* and *Chara muelleri*, falling water levels trigger an increased allocation to reproductive biomass (Casanova 1994, Casanova and Brock 1999b), whereas some species, such as the annual *Nitella sonderi* do not respond in this way. For others, flowering occurs within about 7-12 weeks after inundation.

Protection of water quality is an important part of water management for these plants.

Regeneration

The long-term survival of both annual and perennial Charophytes in wetlands with periodic drying, and in particular in wetlands with an ephemeral or an intermittent water regime, depends on matching water regime with oospore seed bank requirements.

Oospores, like seeds, may be dormant when first released from the parent plant. Dormant oospores accumulate in soils and sediments as seed banks. The numbers of oospores and the number of species in seed banks can be high. In one New England wetland, five Charophyte species occurred in the seed bank, and one of these, *Nitella subtilissima*, had 19,100 oospores per litre of sediment (Casanova and Brock 1990). Unless recharged, the density of oospores in the seed bank decreases with time, due to predation, wet-dry and cold-warm conditions, and to death of oospores. Time-to-death is a species-specific characteristic that varies between species: *Chara muelleri* oospores survived at least 18 months (Casanova and Brock 1996).

Like seeds, oospores may be dormant when first released from the parent plant (Casanova and Brock 1990.

Germination of oospores occurs under water, hence flooding is essential. Critical aspects of water regime for successful germination and establishment appear to be season and duration.

Charophyte species do not have a uniform response to season of flooding. Some species germinate adequately regardless of season of flooding, but a few have well-defined seasonal preferences. For example: the germination rate for *Nitella cristata* is much higher after the seed bank has been chilled than after being warmed (Casanova and Brock 1996); this species is also a winter-grower in the Paroo system (John Porter, pers. comm. 2000). *Lamprothamnium* also has strong seasonal cues. Oogonia collected from the Coorong, South Australia, germinated at temperatures of 16 and 20^{o}C, but not at 12^{o}C (Delroy 1974); on the Paroo, *Lamprothamnium* shows a marked seasonal changes in biomass, peaking in warmer months (John Porter, pers. comm. 2000).

Duration is critical because for some species, the seed bank must be flooded for 15-20 days before germination begins, and must last for approximately 50 days to ensure that oospore germination is completed (Casanova and Brock 1996). Duration is even more critical for establishment (notionally, reaching 3 cm height in experimental conditions), and varies between species, ranging from mean of 6 weeks for *Chara muelleri* to 10 months for *Chara australis* (Casanova and Brock 1999a).

REFERENCES

Aston, H.I (1973) *Aquatic plants of Australia*. Melbourne University Press.

Brock, M.A. (1985). Are Australian salt lake ecosystems different ? - Evidence from the submerged aquatic plant communities. *Proc. Ecol. Soc. Aust*. **14**:43-50.

Casanova, M.T. (1994). Vegetative and reproductive responses of Charophytes to water-level fluctuations in permanent and temporary wetlands in Australia. *Aust J. Mar. Freshw Res*. **45**: 1409-19.

Casanova, M.T. (1996). What determines charophyte distribution in Australia? Proc. 2nd International symposium on extant and fossil Charophytes, Madison (Wisconsin), p.4.

Casanova, M.T. and Brock, M.A. (1990). Charophyte germination and establishment from the seed bank of an Australian temporary lake. *Aquatic Botany* **36**:247-254.

Casanova, M.T. and Brock M.A. (1996). Can oospore germination patterns explain charophyte distribution in permanent and temporary wetlands? *Aquatic Botany* **54**:297-312.

Casanova, M.T. and Brock M.A. (1999a). Life histories of charophytes from permanent and temporary wetlands in eastern Australia. *Australian Journal of Botany* **47:**383-397.

Casanova, M.T. and Brock M.A. (1999b). Charophyte occurrence, seed banks and establishment in farm dams in New South Wales. *Australian Journal of Botany* **47:**437-444.

Delroy, L.B. (1974). The food of waterfowl (Anatidae) in the southern Coorong saltwater habitat of South Australia. *South Australian Ornithologist* **26**:157-163.

Entwisle, T.J., Sonneman, J.A. and Lewis, S.H. (1997). *Freshwater algae in Australia*. Sainty and Associates, Sydney.

Farrer, S.L. (Ed.) (1999). Biology of Charophytes. *Australian Journal of Botany* **47(3).** CSIRO, Australia.

Feist, M and Soulié-Märsche, I. (1999) Preface. *Australian Journal of Botany* **47**(3) iii.

McCourt, R.M., Karol, K.G., Casanova, M.T. and Fesit, M. (1999). Monophyly of genera and species of Characeae based on rbcL sequences, with special reference to Australian and European *Lychnothamnus barbatus* (Characeae: Charophyaceae). *Australian Journal of Botany* **47**:361-69.

Garcia, A. (1999). Charophytes flora of south-eastern South Australia and south-western Victoria: Systematics, distribution and ecology. *Australian Journal of Botany* **47:**407-426.

Roberts, J. (1995). Evaporation basins are wetlands. *Australian Journal of Environmental Management* **2**:7-18.

Roberts, J., Chick, A., Oswald, L. and Thompson, P. (1995). Effect of carp, *Cyprinus carpio* L., an exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. *Marine and Freshwater Research* **46:**1171-80.

Romanowski, N. (1998) *Aquatic and wetland plants*: *a field guide for non-tropical Australia.* University of New South Wales Press, Sydney 2058.

Sainty, G. and Jacobs, S. (1994) *Waterplants in Australia: A field guide*. Third edition. Sainty and Associates, Sydney.

Schwarz, A-M., Hawes, I., and Howard-Williams, C. (1999). Mechanisms underlying the decline and recovery of a Characean community in fluctuating light in a large oligotrophic lake. *Australian Journal of Botany* **47**:325-336.

Wood, R.D (1972). Characeae of Australia. *Nova Hedwigia* **22**:1-120.

Ribbonweed

Vallisneria americana

Ribbonweed, *Vallisneria americana*, is a perennial submerged macrophyte, also known as ribbon grass or eel grass. Leaves are strap-like, growing from the base, and are thin, ie only a few cells thick. These lack a protective layer so appear almost translucent under water and desiccate rapidly when out of the water above water. Leaf length is variable, depending on growing conditions: in shallow wetlands, leaves may be less than 15 cm long, but in deep lakes leaves may be as much as 5 metres long. The plant is stoloniferous.

Life cycle

Vallisneria americana is dioecious, that is the male and female flowes are on separate plants. Flowers are produced underwater but fertilisation occurs at the water surface; after the flower is fertilised, the peduncle or stem of the flower coils drawing the fertilised flower with the developing fruit under water where the fruit develops (Aston 1973). Flowering occurs through summer; and a white surface film of pollen can be seen in calm conditions.

Plants need to grow several years before they start flowering (Surrey Jacobs, pers. comm. 2000). Regeneration and dispersal to new habitats, may be as seed or plant fragments; however expansion within existing habitats is probably entirely vegetative, through stoloniferous expansion, re-growth from tubers or re-growth from plant fragments.

Re-growth from turions, which are compact over-wintering buds, as recorded for *Vallisneria americana* in North America, is unlikely in Australia, as there have been no field records of turions.

Species in Australia

Vallisneria americana is one of the most common and widespread aquatic plant species in the southern parts of the Murray-Darling Basin; *Vallisneria nana* occurs in northern areas (Jacobs and Frank 1997).

Earlier records of *Vallisneria spiralis* and *Vallisneria gigantea* from within the Murray-Darling Basin are probably *Vallisneria americana*. Other species of *Vallisneria* also occur in Australia (Sainty and Jacobs 1994, Romanowski 1998).

The taxonomy of *Vallisneria americana* is problematic. Although the Australian species currently has the same name as the North American species, DNA analyses are underway which suggest that the species are different: this will need to be confirmed, and taxonomic revisions prepared. In the meantime, it is unwise to apply ecological information of the North American species to the Australian *Vallisneria americana* (Surrey Jacobs, pers. comm., 2000).

Distribution and Abundance

Vallisneria americana is one of the most common and widespread aquatic plants in the Murray-Darling Basin. It is found in standing water and flowing water systems such as wetlands, lakes and rivers and creeks. It can form extensive monospecific beds in a range of aquatic habitats including natural wetlands, modified systems such as weirpools and storages, and constructed habitats such as irrigation systems and urban lakes.

Ribbonweed beds occur in shallow and deep water. In Lake Gininderra, ACT (Moore 1992), it occurred in water 5.5 m deep; with the most vigorous plants at 1.5 m; in Lake Liddell, NSW, it reached 6 m (Royle and King 1991). The actual depth than can be colonised is determined by light penetration through the water, which is influenced by turbidity (eg Blanch *et al.* 1998).

In many rivers and wetlands in the Murray-Darling Basin, the abundance of *Vallisneria americana* has gone through cycles of increase and decrease since European settlement. Lake Cargelligo experienced huge and problematic growths of *Vallisneria* in the 1960s but in the 1970s-1980s its abundance was dramatically reduced (Roberts and Sainty 1996). Similar declines have been noted in other modified wetlands and are widely attributed to carp and to turbidity. Although both are demonstrably feasible mechanisms (Blanch *et al.* 1998, Roberts *et al*. 1995), the occurrence of *Vallisneria* beds in the presence of carp and in turbid conditions shows such declines are not a simple cause-effect. Changes in constructed lakes have been linked to turbidity and nutrient inputs (eg Royle and King 1991, Moore 1992).

Dense growths of Ribbonweed can be a problem in irrigation and water delivery systems as these reduce channel hydraulic capacity.

Submerged macrophytes, such as *Vallisneria americana*, are important for small, macro- and micro-fauna, fulfilling many functions such as refuge, nursery and larder. No specific habitat attributes of *Vallisneria americana* have been documented.

Australian studies

Various aspects of growth of *Vallisneria americana* have been studied: field-based estimates of annual production and seasonal growth patterns (Briggs and Maher 1985), leaf decomposition rates (Briggs *et al.* 1985), leaf permeability to gasses (McFarlane 1992), effect of underwater light climate on leaf and shoot growth (Blanch *et al.* 1998), changes in distribution and abundance of *Vallisneria* and other submerged macrophytes in a lake (Royle and King 1991), and growth patterns in relation to depth and changing lake water quality, mainly turbidity and filterable reactive phosphorus (Moore 1992).

Maintenance

Vallisneria americana is a submerged plant with little protection against desiccation. Its growth is strongly seasonal. In a flooded wetland in western NSW, it took 9-10 months for canopy to complete its growth cycle. Canopy was initiated in spring, peaked in late summer, unless curtailed by drawdown, then died back at the beginning of winter (Briggs and Maher 1985).

Critical aspects of water regime are water depth and flood duration. Water needs to be deep enough to accommodate leaf extension during main growing season: a minimum of one metre is suggested, based on Briggs and Maher (1985), but no deeper than 2 m if water is turbid, eg 80 NTU (Blanch *et al.* 1998). Flood duration must be long enough for canopy to complete all phases from spring initiation to autumn build-up of underground storage. In most cases this means *Vallisneria* occurs in lakes and wetlands and parts of river channels which are permanently flooded or flooded for several years at a time.

Season of flooding is not so important, and *Vallisneria* established successfully in experimental pots flooded at different times (Nielsen and Chick 1997).

Water quality, especially turbidity, is important. *Vallisneria americana* is remarkably resilient to low light levels, with a bet-hedging strategy of allocating resources to storage organs rather than canopy. Plants survived low light levels in summer-autumn period for three months (Blanch *et al.* 1998). Turbidity determines the point at which no net growth occurs: plant survival under such adverse conditions is therefore determined by how long these turbid conditions last. This can be modelled using a simple experimentally-derived model (Blanch *et al*. 1998).

Regeneration

Vallisneria expands laterally by establishing daughter plants adjacent to parent plant by developing and extending stolons. The triggers for stoloniferous growth and development of daughter plants has not been studied. It has been observed in riverine field populations in South Australia in autumn, and in glasshouse experiments in December.

The conditions for successful germination and seedling establishment have not been specifically studied for Australian material of *Vallisneria americana*. Seed bank studies suggest germination can occur in all seasons (Britton and Brock 1994); germination is not light dependent and is rapid, occurring in 7 days (Aston 1973).

North American studies on germination, establishment and propagation of *Vallisneria americana* are not readily transferred to climate of the Murray-Darling Basin. These largely originate from regions with a short growing season and a cold winter (eg Korschgen and Green 1988).

REFERENCES

Aston, H.A. (1973). *Aquatic plants of Australia*. Melbourne University Press, Melbourne.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1998). Growth and recruitment in *Vallisneria americana* as related to average irradiance in the water column. *Aquatic Botany* **61**:1810-205.

Briggs, S.V. and Maher, M.T. (1985). Limnological studies of waterfowl habitat in south-western New South Wales. II. Aquatic macrophyte productivity. *Aust J. Mar. Freshw. Res*. **36**:707-15.

Briggs, S.V., Maher, M.T. and Tongway, D.J. (1985). Dry matter and nutrient loss from decomposing *Vallisneria spiralis* L. *Aquatic Botany* **22**:387-392.

Britton, D.L. and Brock, M.A. (1994). Seasonal germination from wetland seed banks. *Aust. J. Mar Freshw. Res*. **45**:1445-57.

Jacobs, S.W.L. and Frank, K.A. (1997). Notes on *Vallisneria* (Hydrocharitaceae) in Australia, with descriptions of two new species. *Telopea* **7**:111-118.

Korschgen, C.E. and Green, W.L. (1998). *American Wildcelery (Vallisneria americana): ecological considerations for restoration.* United State Department of the Interior, Fish and Wildlife Service. Fish and Wildlife Technical Report 19.

MacFarlane, J. J. (1992). Permeability of the cuticle of *Vallisneria spiralis* to carbon dioxide and oxygen. *Aquatic Botany* **43**:129-135.

Moore, J. (1992). *Growth of Vallisneria gigantea in Lake Gininderra, Australian Capital Territory*. Unpub. Hons thesis (Applied Science), University of Canberra.

Nielsen, D. and Chick, A.J. (1997). Flood mediated changes in aquatic macrophyte community structure. *Mar. Freshw. Res*. **48**:153-7.

Roberts, J., Chick, A., Oswald, L. and Thompson, P. (1995). Effect of carp, *Cyprinus carpio* L., an exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. *Marine and Freshwater Research* **46:**1171-80.

Roberts, J. and Sainty, G. (1996). *Listening to the Lachlan*. Sainty and Associates, Potts Point, Sydney.

Romanowski, N. (1998). *Aquatic and Wetland Plants: a field guide for non-tropical Australia*. University of New South Wales press, Sydney.

Royle, R.N. and King, R.J. (1991). Aquatic macrophytes in Lake Liddell, New South Wales; biomass, nitrogen and phosphorus status, and changing distribution from 1981 to 1987. *Aquatic Botany* **41**:281-298.

Sainty, G.R. and Jacobs, S.W.L. (1994). *Waterplants in Australia: a field guide*. Third edition. Sainty and Associates, Potts Point, Sydney.

Summary Sheet: Submerged Macrophytes

Maintenance of Established Submerged Macrophytes
Charophytes Sustained flooding, at least 25 cm deep. For ephemeral and intermittent wetlands, flood duraiton of 16+ weeks
Ribbonweed *Vallisneria americana* Plants desiccate and die if exposed so need permanent flooding or flooding long enough to allow the plant to grow and the canopy to re-establish, probably at least 8 months if flooded in late winter, longer if flooded earlier. Drawdown in spring or summer will mean peak canopy biomass is not reached, and if this recurs, then vigour may be negatively affected. Turbidity reduces light penetrating the water, and if water is deep, plant growth will cease.
Regeneration
Charophytes For regeneration from oospores, water regime requirements depend on what types of life history being targetted.
Ribbonweed *Vallisneria americana* *Insufficient information*

WETLAND HERBS AND FORBS

Wetland herbs and forbs means those non-woody plants typical of wetlands, particularly shallow wetlands and inundated floodplains, as well as billabongs. On floodplains, these may form complex patterns with communities forming mosaics; in wetlands such as billabongs, the communities tend to form concentric patterns referred to a zonation: these are the result of the interplay of differences in depth tolerance and competition.

Focusing on individual species can be appropriate when a species dominates large areas, such as in parts of the Macquarie Marshes. This is not the case in many wetlands as here species distribution changes over short spatial and temporal scales. This makes it necessary to supplement species-based information with other types of knowledge. Examples are community attributes or ecological groups, such as growth form or plant functional types.

Growth form

Plants grouped by growth form have similar morphology.

The five growth forms used in this Source Book are based on relationship of key plant organs – roots (nutrient uptake, sediment oxidation) – and leaves (photosynthesis) - to substrate and water column. Growth form is thus a simplified summary of where a plant obtains its essential resources of carbon dioxide, light energy and growth nutrients (from substrate, water column or air). This means it is possible to make coarse inferences regarding water regime requirements and tolerances.

This can be an advantage if a species is unknown, or if there is no relevant ecological or water regime information. However, there are disadvantages: for example, growth-form refers to adult plant so does not describe regeneration processes.

Emergent: leaves grow through water into air, roots in wet-moist sediment. Examples are sedges, rushes, Cumbungi and the erect grasses such as *Phragmites*; aquatic herbs such as milfoils which have part of leaf canopy above water.

Floating-leafed: leaves on water surface in contact with water and air, stem or petiole in water, roots in sediment. Examples are Floating Pondweed *Potamogeton tricarinatus*, water lillies *Nymphaea* spp., Swamp Lily *Ottelia ovalifolia*.

Free-floating: leaves on water surface or erect in air, roots in water. Examples are *Azolla* spp., and duckweeds *Lemna* and *Spirodela.*

Submerged: leaves in water, roots in sediment. Examples are Ribbonweed, *Vallisneria* spp, charophytes, *Ruppia* spp., *Lepilaena* spp., *Zannichellia palustris*; and some *Potamogeton* spp. Species may have all or most of their leaves underwater, with an apex or a terminal rosette of leaves just breaking surface, as in *Callitriche* spp and several milfoils *Myriophyllum* spp.

Floating stem; leaves on water, stem through water and on surface, roots in sediment. Examples are Wavy Marshwort *Nymphoides crenata*, Water Primrose *Ludwigia peploides*.

These five growth forms cover most herbs and forbs in shallow wetlands, with the following exceptions: submerged free-floating (leaves and roots in water) such as Hornwort *Ceratophyllum*, *Lemna trisulca*.

Other and different systems are in use even in Australia (eg Brock 1997, Brock and Casanova 2000, Sainty and Jacobs 1994). There is considerable overlap between these, with the differences being due to the intended purpose, whether identificaiton, or as ecological summary. There is no standard set of words to use.

Plant Functional Types

Plants with similar responses to their environment are a functional type.

Brock and Casanova (1997) used responses of over 60 species to water regime (presence and absence of water) to define a number of wetland plant functional types. They combined information relating to the responses of three stages in the life cycle (germination and establishment, growth, and reproduction) to water. This information was based on a suite of experiments (on germinating seed banks and establishment), on scientific literature and on field observations.

The result was three groups of functional types (Brock and Casanova 2000).

Terrestrial: plants intolerant of being flooded.

Amphibious: tolerant of being flooded and of being exposed, by either tolerating or responding to fluctuations in water level. There are two main types: Fluctuation-Tolerators, and Fluctuation-Responders.

Submerged: intolerant of drought or dry conditions.

Most of the plant species found in wetlands and floodplains fit in to the Amphibious functional type. This includes growth forms such as trees, shrubs and emergent macrophytes that tolerate water level changes; and floating-leafed and semi-emergent that respond to water level changes. Submerged macrophytes fit into the Submerged functional type (Brock and Casanova 2000).

Community Studies

In community studies, plant responses to water regime are described using community attributes instead of species behaviours. Typical attributes are: measures of abundance (biomass, cover, density), measures of growth and vigour (productivity, height), and measures of community composition (species richness, diversity indices).

Only a few studies have explored or monitored responses of established plants to water regime at the community level:

The effects of flood frequency (0, 1 and 2 per year), timing (spring, summer) on species richness and productivity were investigated in a replicated field study in Gulpa Forest, NSW (Robertson *et al.* 2000); the effect of an autumn flood on growth responses and productivity of dominant wetland and floodplain species was monitored on the floodplain of the Goulburn River, Vic (Nias 1999); the effect of water level stability (stable, natural and two seasonal variations) on species richness was investigated in a replicated experiment using ground tanks as artificial billabongs (Nielsen and Chick 1997).

Two points to note: First, all these studies are for billabongs in the southern parts of the Murray-Darling Basin where the pre-regulation water regime was winter-spring flooding at near annual frequency. Second, because these studies investigated only a subset of all water regime components, their findings are not global but apply only to the treatments used.

Only two regeneration studies based on natural seed banks have addressed community attributes:

The effects of season (spring, summer, autumn, winter) and degree (moist, submerged) of flooding on species richness and abundance of germinating seeds was investigated in a replicated experiment using sediments from five lagoons on the New England Tablelands (Britton and Brock 1994); The effect of short-term variations in three aspects of water regime (depth, duration, frequency), singly and in selected combinations, were investigated in a 4-month summer-autumn replicated experiment (Casanova and Brock 2000).

Fluctuating Water Levels

Long and short-term variability is one of the characteristics of a billabong water regime.

Plant adaptations to fluctuating water levels through the growing season include:

flexible stems

Stem flexibility allows plants to accommodate small (estimated 5-10, possibly 20 cm) changes in water level whilst maintaining their leaves in more favourable growing conditions (light, carbon dioxide) on the water surface.

Examples are: plants with floating stems, such as Water Primrose *Ludwigia peploides*, Red Milfoil *Myriophyllum verrucosum*, and Wavy Marshwort *Nymphoides crenata,* which are rooted at the shoreline and trail out over the water into the current; plants with floating leaves and non-rigid petioles (a stem leaf) such as Water Lily *Nymphaea* or Floating Pondweed *Potamogeton tricarinatus* that are rooted in the bottom muds. Some species with floating leaves and non-rigid petioles can grow in both still and flowing water, for example

Nardoo *Marsilea drummondii*, seen in flowing floodwater, 1 metre deep (Roberts, pers. obs, Chowilla floodplain, December 1993).

morphological plasticity

Changing plant morphology allows plants, mainly herbs, to continue to grow under a range of conditions.

Examples are: plants such as *Myriophyllum variifolium* that develop shallow and deep water forms, and develop leaves of different shape and size, and also internodes of variable rather than fixed length (Brock and Casanova 1991); larger leaf areas for surface-floating leaves of *Marsilea mutica* (Yen and Myerscough 1989b).

elongation

Plants with erect and relatively rigid stems or culms, such as most monocotyledonous emergent macrophytes, avoid the negative effects of a sudden increase in water level by stem elongation. Without elongation, the stem or culm becomes completely or partly submerged and growth is reduced as carbon uptake is reduced or ceases.

An example is: *Bolboschoenus medianus* where elongation is due to an increase in inter-node length (Blanch *et al*. 1998).

sensitivity to water depth changes

Relatively small changes in water depth, in the order of 10 to 20 cm, can cause large changes in ratio of aboveground (photosynthetic, growing) to belowground (storage, resource acquisition) biomass and affect resource allocation.

Examples are: River Club-rush *Bolboschoenus medianus* growing close to the waterline allocated 4-7 times more biomass to leaves than to roots, whereas plants grown 20 cm and 40 cm above the waterline allocated 3-4 times more biomass to roots (Blanch *et al.* 1996, 1998).

rapid growth responses

Floods of short duration offer only a limited time for plants to grow and complete their life-cycle, and species that can grow rapidly will be more likely to complete their life cycle.

Examples are: New leaves of *Myriophyllum variifolium* appear within a few days of flooding (Brock and Casanova 1991); *Ludwigia peploides* can grow from fragments to the water surface, reaching 40 cm in 2 days or 100 cm in 6 days (Yen and Myerscough 1989b); *Marsilea mutica* can grow 10 cm to water surface overnight or reach 100 cm in 6 days (Yen and Myerscough 1989b); *Villarsia reniformis* has rapid petiole extension in response to flooding (Cooling 1996); leaf extension rates of 8-9 mm day^{-1} noted in winter for *Pseudoraphis spinescens*, *Myriophyllum crispatum*, *Ludwigia peploides* and *Triglochin procera* (Ward 1991); *Nymphoides spinulosperma* was flowering and fruiting within 2 months after lagoon inundation (Aston 1997).

Increase in Water Levels

Plant adaptations to a sustained increase in water depth are:

biomass re-allocation

Plants with aerial leaves or photosynthetic stems will lose some of their photosynthetic capacity if water levels rise, and remain high. Perennial herbs with underground organs such can draw on underground carbohydrate storage in rhizomes or tubers and use it to grow new and taller shoots.

Species differ in height, amount stored and growth rates, hence they also differ in what depth changes they can respond to, and what is outside their respone range.

Examples are: *Baumea arthrophylla* can accommodate a 50 cm rise in water level but not 100 cm (Rea and Ganf 1994): three months after water level rose from 0 to 50 cm, *Baumea* had grown more shoots and more leaves in the deeper water but underground biomass was reduced by 50%.

Regeneration

Regeneration strategies for billabong plants include germination from seed bank and re-growth from vegetative propagules such as turions (dense compact buds) or from plant fragments. Turions are usually formed prior to winter. Plant fragments are the result of wave action, strong flows, or stock disturbance which physically damage the parent plant, causing it to break up. The resulting fragments may then be distributed by wave action, water flow or water birds. Being fragments, these plant parts are not hardy (like seeds) and may dry out within a few days, particularly during hot conditions.

Germination studies have been done on single species, on pairs of species such as *Typha domingensis* and *Triglochin procera* (Nicol and Ganf 2000), or *Juncus articulatus* and *Glyceria australis* (Smith and Brock 1998); and on whole seed banks. Seed bank studies have been done for different habitats: rice fields

(McIntyre 1985), lagoons on the New England Tablelands (eg Britton and Brock 1994, Casanova and Brock 2000).

Seed germination occurs under water or on saturated muds, such as left by flood recession. A major effort in early seed bank studies went into determining which of these two habitats, or both, was preferred for individual species or groups of species (eg McIntyre 1985).

It is now clear that wet muds are a better germination habitat for a range of wetland plants: emergent macrophytes; herbs of the riparian forest understorey, such as *Wahlenbergia fluminalis*, *Ranunculus pumilio, Epilobium hirtigerum* and *Centipeda cunninghamii*; also some widespread, common introduced annuals such as *Polygonum aviculare*, *Conyza albida* and *Rumex crispus* (McIntyre 1985).

The water regime conditions favouring establishment, which is the phase after germination, were determined for a range of species and functional types by Casanova and Brock (2000).

Water regime: individual herb & forb species

What is known of the water regime tolerated or required by individual herb and forb species is summarised here. These are mostly based on field observations of species distributions in two habitats, the banks of the River Murray, South Australia (Blanch *et al.* 1999) and wetlands in north-central Victoria (Ward 1996), and supplemented by a few experimental studies.

These two habitats do not encompass the full habitat and climate range of these species, so these requirements should be treated as an approximate guide only.

Isotoma fluviatilis: in northern Victoria, found where flooding is shallow, less than 10 cm, relatively short, 1-3 months long, and flooding occurs in spring-summer (Ward 1996).

Ludwigia peploides: found where flooding occurs in winter-summer and lasts for 8-10 months in northern Victoria, to depth of 1 metre (Ward 1996). Seeds germinate under water and on wet soil but require light (Yen and Myerscough 1989b). Germination is temperature sensitive, with no germination at 10^{o}C compared with an optimum at 30^{o}C: at this temperature, germination starts within a day of flooding and is completed in less than 5 days, but at higher and at lower temperatures, germination is delayed, and at 40^{o}C success rate is halved (Yen and Myerscough 1989b).

Marsilea drummondii: in northern Victoria, found where flooding occurs in spring-summer, lasts 1-6 months, and is shallow, less than 10 cm deep (Ward 1996);

Marsilea mutica: once sporocarps are cracked open, germination is rapid and leaves develop on gametophyte in 5-7 days (Yen and Myerscough 1989b).

Nymphoides crenata: found where winter-summer floods last 9-10 months in northern Victoria, and are up to 1 metre deep (Ward 1996).

Ottelia ovalifolia: found in shallow waters, to 50 cm deep, where flooding lasts 2-6 months, from winter to summer, for northern Victoria (Ward 1996).

Phyla canescens: on banks of the River Murray, SA, occurs where flooding totals 66-80 days per year, and does not exceed 60 cm (Blanch *et al.* 1999): described as tolerant of shallow inundation and capable of extending to water surface, but also described as intolerant of inundation in turbid water for 4-8 weeks (Lucy *et al.* 1995).

Potamogeton tricarinatus: in northern Victoria occurs where flooding lasts 6-12 months per year, occurs in winter to summer, in water 50 cm deep (Ward 1996).

Pratia concolor: on banks of the River Murray, SA, this occurs where the number of days flooded totals 23-53 per year, and depths are not greater than 60 cm (Blanch *et al.* 1999); in northern Victoria, it is found where flooding lasts 1-3 months over spring-summer but in shallows, less than 10 cm deep (Ward 1996).

Ranunculus inundatus: in northern Victoria found where flooding occurs in winter-spring, lasts for 1-9 months, with an optimum of 3 months, and depth is shallow, less than 10 cm (Ward 1996).

Triglochin procerum: optimum duration in northern Victoria is 6 months, typically in depths of 50 cm but up to 1.5 m, preferably in winter-summer, but can tolerate as little as 1 month and as much as 8 months (Ward 1996); at Bool Lagoon, *Triglochin procerum* can tolerate water level increases from 0 to 50 cm, from 50 to 100 cm and from 0 to 100 cm (Rea and Ganf 1994).

REFERENCES

Aston, H.I. (1997). *Nymphoides spinulosperma* (Menyanthaceae): a new species from south-eastern Australia. *Muelleria* **10**:21-25.

Blanch, S.J., Burns, A., Vilizzi, L. and Walker, K.F. (1996). *Ecological effects of shallow winter-spring flooding in the Lower River Murray, 1995.* Report to Natural Resources Management Strategy, Murray-Darling Basin Commission. November 1996.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1998). Growth and resource allocation in response to flooding in the emergent sedge *Bolboschoenus medianus*. *Aquatic Botany* **63**:145-160.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1998). Growth and recruitment in *Vallisneria americana* as related to average irradiance in the water column. *Aquatic Botany* **61**:181-205.

Blanch, S.J., Ganf, G.G. and Walker, K.F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management* **15**:43-62.

Briggs, S.V. and Maher, M.T. (1985). Limnological Studies of Waterfowl habitat in south-western New South Wales. II. Aquatic macrophyte productivity. *Aust. J. Mar. Freshw. Res*. **36**:707-715.

Brix, H., Sorrell, B.K. and Orr, P.T. (1992). Internal pressurization and convective gas flow in some emergent freshwater macrophytes. *Limnol. Oceanogr*. **37**:1420-1433.

Britton, D.L. and Brock, M.A. (1994). Seasonal germination from wetland seed banks. *Aust. J. Mar. Freshwater Res*. **45**:1445-57.

Brock, M.A. (1991). Mechanisms for maintaining persistent populations of *Myriophyllum variifolium* J. Hooker in a fluctuating shallow Australian lake. *Aquatic Botany* **39**:211-219.

Brock M A (1997) *Are there seeds in your wetland? Assessing Wetland Vegetation*. Land and Water Resources Research and Development Corporation, Canberra. 16 pp.

Brock, M.A. and Casanova, M.T. (1991). Vegetative variation of *Myriophyllum variifolium* in permanent and temporary wetlands. *Aust. J. Botany* **39**:487-496.

Brock, M.A. and Casanova, M.T. (1997). Plant life at the edge of wetlands: ecological responses to wetting and drying patterns. In: N. Klomp and I. Lunt (eds). “Frontiers in Ecology: building the links”. Elsevier Science. Oxford.

Brock M.A. and Casanova M.T. (2000) *Are there plants in your wetland? Revegetating wetlands.* LWRRDC, UNE, DLWC and EA. 16 pp.

Casanova, M.T. and Brock, M.A. (2000). How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant Ecology* **147**:237-250.

Cooling, M. (1996). *Adaptations of aquatic macrophytes to seasonally fluctuating water levels*. Unpub PhD, Department of Botany, University of Adelaide. December 1996.

Lucy, M., Powell, E., McCosker, R., Inglis, G. and Richardson, R. (1995). *Lippia (Phyla canescens): a review of its economic and environmental impact on floodplain ecosystems in the Murray-Darling Basin*. Agdex 642/040.

Madsen, J.D. and Adams, M.A. (1988). The germination of *Potamogeton pectinatus* tubers: environmental control by temperature and light. *Canadian J. Botany* **66**:2523-2526.

McIntyre, S. (1985). Seed reserves in temperate Australian rice fields following pasture rotation and continuous cropping. *J. Applied Ecology* **22**:875-884.

Nias, D.J. (1999). *Carbon dynamics and ecology of an Australian temporary floodplain wetland.* Unpub PhD thesis, Monash University.

Nielsen, D.L. and Chick, A.J. (1997). Flood-mediated changes in aquatic macrophyte community structure. *Mar. Freshwater Res*. **48**:153-7.

Nicol, J.M. and Ganf, G.G. (2000). Water regimes, seedling recruitment and establishment in three wetland plant species. *Mar. Freshw. Res*. **51**:305-9.

Rea, N. and Ganf, G.,G. (1994). Water depth changes and biomass allocation in two contrasting macrophytes. *Aust. J. Mar. Freshw. Res.* 45:1459-68.

Robertson, A.I., Bacon, P. and Heagney, G. (2000.) The responses of floodplain primary production to flood frequency and timing. *J. Applied Ecol*.

Sainty, G. and Jacobs, S. (1994) *Waterplants in Australia: A field guide*. Third edition. Sainty and Associates, Sydney.

Siebentritt, M.A. and Ganf, G.G. (2000). Influence of abiotic and biotic factors on two co-occurring species of *Bolboschoenus*. *Marine Freshwater Research* **51**:73-81.

Smith, R.G.B. and Brock, M.A. (1998). Germination potential, growth patterns and reproductive effort of *Juncus articulatus* and *Glyceria australis* in temporary shallow wetlands in Australia. *Wetlands Ecology and Management* **5**:203-214.

Ward, K.A. (1991). *Investigation of the flood requirements of the Moira grass plains in Barmah Forest, Victoria:* Final Report. Department of Conservation and Environment, Shepparton, Victoria.

Ward, K. (1996). Flood requirements of vegetation for the rehabilitation of Lake Mokoan. Department of Natural Resources and Environment. Draft report. 6pp.

Yen, S. and Myerscough, P.J. (1989a). Co-existence of three species of amphibious plants in relation to spatial and temporal variation: Field evidence. *Aust. J. Ecology* **14**:291-303.

Yen, S. and Myerscough, P.J. (1989b). Co-existence of three species of amphibious plants in relation to spatial and temporal variation: Investigation of plant responses. *Aust. J. Ecology* **14**:305-318.

Summary Sheet: Herb & Forb Communities

Maintenance of Established Herb and Forb Communities

Species Richness

Season & Depth: Species richness is higher after spring flood than after a comparable length summer flood; and is higher in shallow (< 30 cm) water than water more than 30 cm deep.

Season: Species richness is higher under a spring flood regime than under a summer flood regime.

Water level stability: Species richness is higher under a seasonally fluctuating water regime than under a permanent and stable water regime, and both spring and summer flooding result in species richness that is higher than stable water level conditions. Species richness declines through time when water levels are stable but no decline evident when water levels fluctuate.

Diversity: Growth form or Functional Types

Water level stability: Stable water levels exclude growth forms specific to fluctuating conditions.

Abundance

No information.

Production and Productivity

Season and Depth: Spring flooding results in higher daily production, as g m^{-2} d^{-1}, than does summer flooding; daily production is higher in shallow (<30 cm deep) than water more than 30 cm deep.

Duration: Species differ in time required after an autumn flood to reach maximum biomass.

Regeneration

Species Richness

Season: Autumn flooding resulted in higher species richness in germinating seed banks and summer the lowest; and spring similar effect as autumn.

Depth: No differences in species richness in plants establishing in depths 5-60 cm, but species richness much higher in moist soils.

Duration: Seedling species richness declines as flood duration increases from 4-16 weeks.

Diversity: Growth-form or Functional Types

Depth and Duration and Frequency: Specific combinations of depth, duration and flood frequency lead to specific Functional Types of seedlings being dominant: Moist conditions leads to Terrestrial seedlings dominating; short frequent floods leads to Amphibious seedlings dominating; Continuous floods leads to Submerged seedlings dominating.

Abundance

Season: Number of seedlings germinating was highest in autumn, and lowest in summer.

Depth and Duration: No effect on biomass of establishing seedlings after 16 weeks at depths of 5-60 cm or in durations of 4-16 weeks but much higher in damp soil.

Production and Productivity

No information