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Environmental Watering for Understorey and Aquatic Vegetation in The Living Murray Icon Sites

A literature review and identification of research priorities relevant to the environmental watering actions of flow enhancement and retaining floodwater on floodplains

Report to the Murray–Darling Basin Authority Project number MD1252

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Capon, S.J., James, C.S., Mackay, S.J. and Bunn, S.E.
Australian Rivers Institute

Griffith University

June 2009

Acknowledgments

Doug Frood, Pathways Bushland & Environment Consultants, Victoria
Kate Stokes, CSIRO Entomology, Canberra
Kathryn Stanislawski, North Central CMA, Victoria
Keith Ward, Goulburn Broken CMA, Victoria
Marcus Cooling, Ecological Associates, South Australia
Matthew Murphy, MDBA, Canberra
Matt Colloff, CSIRO Entomology, Canberra
Mel White, Department of Water Land and Biodiversity Conservation, Adelaide
Melanie Tranter, North Central CMA, Victoria
Rolf Weber, Department of Sustainability & Environment, Victoria
Stuart Little, MDBA, Canberra

MDBA Publication No. 10/12
ISBN (on-line) 978-1-922068-10-1

Authors: Capon, S.J., James, C.S., Mackay, S.J. and Bunn, S.E.

Cover images:

Sedge (*Eleocharis spatheolata*) in Barmah–Millewa Forest icon site (photo by Keith Ward, Goulburn Broken CMA)

Small mouthed hardyhead (photo by Gunther Schmida ©MDBA)

Royal spoonbill adult and chick (photo by Keith Ward, Goulburn Broken CMA)

River red gum in Gunbower–Koondrook–Perricoota Forest icon site (photo by David Kleinert ©MDBA)

Murray–Darling Basin Authority

Postal Address: GPO Box 1801, Canberra ACT 2601

Office location: Level 4, 51 Allara Street, Canberra City, Australian Capital Territory

Tel: (02) 6279 0100, international + 61 2 6279 0100
Fax: (02) 6248 8053, international + 61 2 6248 8053

E-mail: info@mdba.gov.au
Website: www.mdba.gov.au

For further information contact the Murray–Darling Basin Authority office on (02) 6279 0100.

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Executive summary

This report provides a literature review, conceptual models and research priorities addressing retaining floodwater on floodplains and flow enhancement hypotheses relevant to understorey and aquatic vegetation of The Living Murray (TLM) icon sites.

Key floodplain understorey and aquatic vegetation communities of TLM icon sites include; i) ephemeral herb lands, ii) reed-beds, iii) giant rush lands, iv) Moira grass plains, v) lignum shrublands, vi) river red gum forests and woodlands and vii) black box woodlands, all of which are widespread across the majority of icon sites. The Lower Lakes, Coorong and Murray Mouth (LLCMM) and River Murray Channel icon sites, also support relatively unique communities amongst the icon sites such as weir pool communities in the latter. Key floodplain understorey and aquatic plant taxa across these communities include common reed, cumbungi, giant rush, lignum, milfoil, Moira grass, rat's tail couch, ribbon weed and, in the LLCMM, tuberous tassel and large fruit tassel. The condition of floodplain understorey and aquatic vegetation is perceived to be deteriorating in all of the icon sites with the loss of plant diversity from flood dependent and tolerant communities and the encroachment of these communities by more mesic and xeric species as well as weed invasions being the major issues of concern.

Flooding has the potential to interact with each stage of a plant's life history from germination to propagule dispersal. At a general level, there appears to be a reasonable amount of knowledge concerning the effects of flooding on major life history stages of floodplain understorey and aquatic plants and, in some cases, this understanding extends specifically to key taxa of the icon sites. In most cases, however, quantitative thresholds for flow requirements of particular life history processes for key taxa have not been established. This is especially apparent in relation to the effects of flow on processes of plant regeneration, i.e. plant allocation to reproduction, propagule dispersal, vegetative reproduction, germination and establishment.

Floodplain understorey and aquatic vegetation dynamics are typically highly variable both temporally and spatially and are driven primarily by patterns of flooding and drying. In the short-term, vegetation responses to flooding in the icon sites are likely to be determined by flood timing, depth, duration, rate of drawdown, time since last flood and frequency, with the effects of each of these attributes differing amongst key community types. Spatial variation both within and between key community types will be influenced by differences in patterns of flooding and drying over time. Processes of vegetation regeneration, e.g. propagule dispersal and establishment from propagule banks, are likely to be crucial in determining vegetation response to flow interventions. However, these processes also represent a major knowledge gap with very little information concerning the character, condition or contribution of propagule banks or propagule dispersal available for TLM icon sites.

A large number of weeds have been recorded in the icon sites. Species identified as of particular concern are lippia and arrowhead. Other weed species reviewed here were selected to represent life form groups: obligate submerged, free floating, amphibious (emergent and plastic growth forms) and terrestrial. The growth, dispersal and reproduction of weed species is likely to be influenced by the full suite of flow attributes considered here but relevance of hydrological parameters varies between life form groups. Vegetative reproduction is the main and in some cases only (e.g. submerged weeds) mechanism of spread. Sexual reproduction is less common and generally restricted to the amphibious and terrestrial groups. Propagule availability is likely to strongly limit the ability of some weeds to invade a specific site and, in particular, will influence those species intolerant of desiccation (as either an extant plant or reproductive unit) that require re-inoculation each time hydrological conditions become suitable.

Existing methods of data collection for condition and intervention monitoring in the icon sites appear to be thorough and well designed. However, there is a need to further consider data analysis and the conceptual framework within which condition and effectiveness of flow interventions are assessed so that the inherent variability of these systems is given greater recognition.

Priorities for research identified include:

1. Using all available monitoring data across all TLM icon sites in order to i) develop a transferable plant functional group classification for use across all icon sites, ii) an understanding of the inherent temporal and spatial variability of key floodplain and aquatic vegetation communities and how this relates to hydrology, iii) conceptual models that make predictions concerning selected indicators with respect to current hydrological conditions that take into account this inherent variability and iv) preliminary limits of acceptable change in key indicators.
2. Experiments to determine the character and condition of propagule banks and their contribution to vegetation dynamics amongst key floodplain and aquatic vegetation communities as well as hydrological influences on these.

1. Introduction

1.1 Background

The Murray–Darling Basin Authority (MDBA) seeks to address knowledge needs relating to the topic "creation or maintenance of habitat suitable for germination, growth, health and recruitment of native understorey and aquatic vegetation, resulting from flow enhancement or retaining floodwater on floodplains interventions". More specifically, The Living Murray Initiative requires this knowledge to inform the Intervention Monitoring component of its monitoring program and thus support environmental watering decisions for the six Living Murray icon sites. In particular, the MDBA wishes to establish the current state of knowledge regarding relationships between flow and understorey and aquatic vegetation within icon sites and minimise risks associated with future research programs directed towards the improved understanding and management of these communities.

1.2 Project objectives

The specific objectives of this project are:

1. To provide a literature review that:
   - identifies flow characteristics that best create or maintain habitat suitable for the germination of understorey and aquatic vegetation
   - identifies flow characteristics that best create or maintain habitat suitable for the health and growth of understorey and aquatic vegetation
   - identifies flow characteristics that best create or maintain habitat suitable for the recruitment of understorey and aquatic vegetation
   - identifies the risks of weed germination, growth and dispersal with the flow characteristics identified as suitable for native understorey and aquatic vegetation.
2. To develop conceptual models that address the following hypotheses:
   - suitable habitat for native understorey and aquatic vegetation will be created or maintained through retaining floodwater on floodplains
   - the health and growth of native understorey and aquatic vegetation will increase through retaining floodwater on floodplains
   - native understorey and aquatic vegetation will germinate or recruit through retaining floodwater on floodplains
   - suitable habitat for weed vegetation will be created or maintained through retaining floodwater on floodplains
   - suitable habitat for native understorey and aquatic vegetation will be created or maintained through flow enhancement
   - the health and growth of native understorey and aquatic vegetation will increase through flow enhancement
   - native understorey and aquatic vegetation will germinate and recruit through flow enhancement.
3. Identify key knowledge gaps
4. Identify research priorities to address key knowledge gaps.

1.3 Approach and scope

Given the complexity of the field and the short time-frame of the current project, we chose a selection of key floodplain understorey and aquatic taxa and community types to focus on for the literature review and conceptual model components described above. These were selected by reviewing available information concerning floodplain and aquatic vegetation of the icon sites on the basis of their prevalence, structural dominance and ecological significance. Due to the variable quality and availability of this information across icon sites, however, it should be recognised that the absence of a key taxa or community type associated with an Icon Site does not necessarily mean it is not present there at all, but rather the information reviewed here does not highlight its significance. Where possible, we present generic information concerning the effects of flooding and drying on generalised floodplain and aquatic habitats, taxa and communities as well as available information specific to selected taxa and communities. Given the management-orientation of the intended audience of this report, we predominantly use common names for taxa after their first appearance.

The report comprises three main sections; a literature review, conceptual models and finally, identification and prioritisation of knowledge gaps and research priorities addressing these. The literature review itself also comprises three major sections, each examining the effects of flooding on floodplain and aquatic plant habitats, plant life histories and vegetation community dynamics respectively. The first section provides a brief introduction to floodplain understorey and aquatic vegetation of The Living Murray icon sites.

2. Floodplain understorey and aquatic plants of The Living Murray icon sites

2.1 Barmah–Millewa Forest

Site description

The Barmah–Millewa Forest is located downstream of Yarrawonga Weir on the River Murray and incorporates floodplains of both the Murray and Edward rivers. The Millewa Forest occupies 38,115 ha on the northern side of the Murray in New South Wales and the Barmah Forest a further 28,500 ha on the southern side in Victoria (MDBC, 2005a). Together, these forests comprise the largest area of river red gum forest in both the Murray–Darling Basin and in Australia (MDBC, 2005a).

Ecological objectives relevant to understorey and aquatic vegetation

As Ramsar sites, the over-arching management objective for the Barmah and Millewa Forests is 'to maintain and, where practicable, enhance ecological character of (the) floodplain' (MDBC, 2006a). More specifically, the Murray–Darling Basin Ministerial Council's interim ecological objectives and outcomes for the Icon Site are 'to enhance forest, fish and wildlife values, ensuring

i. successful breeding of thousands of colonial waterbirds in at least three years in ten
ii. healthy vegetation in at least 55% of the area of forest (including virtually all of the giant rush, Moira grass, river red gum forest, and some river red gum woodland' (MDBC, 2006a).

An additional 15 ecological objectives relating to vegetation in the Barmah–Millewa Forest Icon Site were identified by McCarthy *et al.* (2006) following a review of policy, planning and legislative documents concerning Barmah Forest. A complete list and prioritisation of these objectives is available in McCarthy *et al.* (2006).

Floodplain understorey and aquatic vegetation

Over 85% of Barmah Forest and 75% of Millewa Forest comprise *Eucalyptus camaldulensis* (river red gum) communities. Low-lying areas close to the river support a range of wetland vegetation communities including *Eleocharis* spp. (spike-rush) meadows, e.g. on Algeboia Plain, *Juncus ingens* (giant rush) rushlands and *Phragmites australis* (common reed) reed-beds (MDBC, 2005a). In areas that are inundated less frequently but too often to support river red gum communities, grass plains dominated by *Pseudoraphis spinescens* (Moira grass, spiny mud grass) occur. *Eucalyptus largiflorens* (black box) communities occur at the highest floodplain elevations.

Numerous vegetation classification schemes and maps have been developed for the Barmah–Millewa Forest including (in MDBC, 2005a):

i. Chesterfield *et al.* (1984): four classes based on structure and dominant species; rushland, grassland, open forest-woodland and woodland-open woodland
ii. Smith (1983): three classes based on the quality of red gum stands; open forest red gum SQI, red gum SQII, red gum SQIII
iii. Maunsell *et al.* (1992): further sub-division of the classes developed by Chesterfield *et al.* (1984) based on understorey associations
iv. Barmah–Millewa Forum (2000): identified four major structural classes; rushlands, grass plains, red gum forests (further divided into SQI, SQII and SQIII) and box forest with an open water category added by Maunsell *et al.* (1992)
v. The Murray Flows Assessment Tool (MFAT) Scientific Reference Panel (SRP) (2003): identified five floodplain vegetation classes; river red gum forest, river red gum woodland, lignum shrubland and rat's tail couch grassland; as well as four wetland vegetation classes including Moira grass and giant rushland
vi. Frood (2005): identified 64 primary structural vegetation units combined to produce approximately 585 vegetation associations and later simplified into 23 Ecological Vegetation Classes (EVCs).

An equivalency table comparing vegetation classification schemes is presented in MDBC (2005a).

Key understorey and aquatic taxa

Carex tereticaulis (terete culm sedge)

Eleocharis acuta (common spike-rush)

Juncus ingens (giant rush)

Ludwigia plepoides (water primrose)

Muehlenbeckia florulenta (tangled lignum)

Myriophyllum crispatum (milfoil)

Phragmites australis (common reed)

Pseudoraphis spinescens (Moira grass, spiny mud grass)

Sprorobolus mitchellii (rat's tail couch)

Triglochin procerum (water ribbons)

Typha spp. (cumbungi)

Condition of floodplain understorey and aquatic vegetation

Understorey vegetation in Barmah Forest has been monitored by Ward (2009a,b, 2007) since 2006 and prior to this by Ward in 1991 and 1994 (Ward, 1992, 1994). The most recent summer and autumn monitoring in 2009 have revealed very little groundcover present with most sites bare or covered by brown leaf litter (Ward, 2009a,b). Over 100 understorey plant species were recorded during summer surveys in 2009 but plant cover was generally less than 10% (Ward, 2009a). Rainfall in November and December of 2008 had resulted in rapid growth and flowering in some understorey species including a number of wetland species, e.g. water primrose, but overall biomass levels remained low. The number of understorey species present by autumn surveys had fallen to around 65 with even lower levels of cover (Ward, 2009b). Regrowth of giant rush and common reed was observed during these surveys in response to some minor flooding from environmental water in Millewa Forest (Ward, 2009b). Elsewhere, however, in known bird breeding sites, giant rush is typically in poor condition being brittle and senescent (Ward, 2009a).

Key issues associated with floodplain understorey and aquatic vegetation

The major ecological issue associated with understorey and aquatic vegetation in the Barmah–Millewa Icon Site is the encroachment of Moira grass plains by both giant rush at the wetter end of the grass plains' extent and river red gum seedlings at higher elevations. An estimated 1,200 ha or 30% of the area occupied by Moria grass plains has been replaced by river red gum communities since 1930 and an additional 1,200 ha lost to giant rush invasion (Chesterfield (1986) in MDBC, 2005a). Encroachment by river red gum seedlings is attributed to the migration of red gum communities into lower elevations of the floodplain that were flooded too frequently in the past (Bren, 1992). Giant rush, in contrast, is spreading into higher floodplain elevations as a result of an increased frequency of shallow floods (MDBC, 2005a). Bren (1992) demonstrated that eventually the Moira grass plains are likely to disappear almost completely as a result of river regulation and the subsequent invasion of grass plains by red gum communities.

2.2 Gunbower–Koondrook–Perricoota Forest

Site description

The Gunbower–Koondrook–Perricoota Forest Icon Site encompasses approximately 50 000 ha of River Murray floodplain downstream of Echuca. The Koondrook–Perricoota Forest accounts for 31,150 hectares on the New South Wales side of the river and the Gunbower Forest occupies a further 19,931 hectares on the Victorian side (MDBC, 2005a). Together, the Gunbower and Koondrook–Perricoota Forests are the second largest area of river red gum forest in the Murray–Darling Basin and Australia after the Barmah–Millewa Forest. Both forests are Ramsar listed and have significant ecological values, particularly in relation to their use by waterbirds and for their floodplain and wetland vegetation. The site comprises numerous floodplain and wetland habitats including permanent and semi-permanent wetlands, creeks and open woodlands (MDBC, 2005a).

Ecological objectives relevant to understorey and aquatic vegetation

The Murray–Darling Basin Ministerial Council's interim ecological objectives and outcomes for the Icon Site are:

i. 80% of permanent and semi-permanent wetlands in healthy condition
ii. 30% of river red gum forest in healthy condition
iii. successful breeding of thousands of colonial waterbirds in at least three years out of ten
iv. healthy populations of resident native fish in wetlands (MDBC, 2006b).

Additionally, the Victorian State Government's vision for the Gunbower Forest is to 'maintain and restore a mosaic of healthy floodplain communities across Gunbower Forest which is representative of the communities which would be expected under natural conditions and which will ensure that native plant and animal species and communities survive and flourish throughout the sites' (MDBC, 2006b).

Specific ecological objectives for the use of environmental water in Gunbower Forest have also been developed for key wetland and vegetation communities (MDBC, 2006b):

i. *Permanent wetlands*: reinstate area to 50% natural and reinstate habitat quality so that species typical of permanent wetlands are present
ii. *Semi-permanent wetlands*: restore 50% of area that has been lost since pre-regulation conditions and restore habitat quality so that species typical of semi-permanent wetlands are present
iii. *River red gum with flood dependent understorey*: restore 50% of area that has been lost since river regulation
iv. *River red gum with flood tolerant understorey*: reduce total area and maintain habitat quality so that species typical of red gum flood tolerant understorey are present
v. *Black box*: maintain the extent and restore habitat quality so that species typical of black box wetlands are present;
vi. *Grey box*: maintain extent and quality
vii. *Watercourses and channels*: reduce transmission of pest plants and animals, restore connectivity and restore habitat quality of Gunbower Creek
viii. *Temporary wetlands*: restore the natural pattern of temporary wetlands within the forest.

Floodplain understorey and aquatic vegetation

River red gum communities cover approximately 70% of Gunbower Forest and 80% of Koondrook–Perricoota Forest and around 60% of this total red gum area has a flood dependent understorey (MDBC, 2005a). In the Gunbower Forest, low-lying, historically permanent wetlands support sparse semi-emergent vegetation, e.g. Moira grass, with some submerged aquatic plants such as *Myriophyllum* spp., and are fringed by emergent sedges and rushes (Cooling *et al*, 2002; MDBC, 2005a). Temporary wetlands also occur throughout the forest across a range of floodplain elevations and these support a variety of aquatic plant communities comprising species such as Moria grass, *Myriophyllum* spp. and *Nymphoides crenata* (waxy marshwort) (Cooling *et al*, 2002). Lower floodplain elevations are occupied by tall river red gum forest with a flood dependent understorey including species such as *Triglochin procerum* (water ribbons), *Paspalidium jubiflorum* (Warrego summer grass) and *Carex tereticaulis* (terete culm sedge, tube sedge) (Cooling *et al*, 2002; MDBC, 2005a). River red gum woodland with a flood tolerant understorey of *Danthonia* spp. (wallaby grasses) and *Themeda* spp. (kangaroo grasses) and terrestrial grass species occurs at higher elevations grading into black box woodland with an understorey of chenopod shrubs and terrestrial grasses in marginal floodplain areas (Cooling *et al.*, 2002; MDBC, 2005a). In the Koondrook–Perricoota Forest, low-lying marshes are dominated by dense emergent and semi-emergent vegetation including *Myriophyllum* spp., Moria grass, sedges and rushes with river red gum forest on the surrounding floodplain. Reed beds, often in association with cumbungi, grasses and aquatic plants, also occur on the floodplain (MDBC, 2005a) and watercourses throughout the forest may be fringed by emergent sedges, rushes and grasses and *Acacia dealbata* (silver wattle) (Cooling *et al.*, 2002).

Vegetation classification schemes developed for the Gunbower–Koondrook–Perricoota Forest are similar to those applied in the Barmah–Millewa Forest and an equivalency table comparing various vegetation classification schemes is presented in MDBC (2005a). Most recently, work conducted by Ecological Associates (in MDBC, 2005a) provides a classification which takes into account the dominant understorey vegetation:

i. permanent wetlands (giant rush and ribbon weed)
ii. semi-permanent wetlands (Moira grass and common reed)
iii. red gum forest with flood dependent understorey
iv. river red gum forest with flood tolerant understorey
v. black box woodland.

Key understorey and aquatic taxa

Amphibromus fluitans (river swamp wallaby grass)

Carex tereticaulis (terete culm sedge)

Eleocharis acuta (common spike-rush)

Danthonia spp. (wallaby grasses)

Juncus ingens (giant rush)

Myriophyllum spp. (milfoil)

Nymphoides crenata (waxy marshwort)

Paspalidium jubiflorum (Warrego summer grass)

Phragmites australis (common reed)

Pseudoraphis spinescens (Moira grass, spiny mud grass)

Themeda spp. (kangaroo grasses)

Triglochin procerum (water ribbons)

Vallisneria americana var. americana (ribbonweed)

Condition of floodplain understorey and aquatic vegetation

Understorey vegetation in the Gunbower Forest and Pollack Swamp in the Koondrook State Forest has been conducted by Australian Ecosystems Pty Ltd since autumn 2005 (Bennetts & Backstrom, 2009). Results from the most recent survey, conducted in spring 2008, indicate that vegetation composition in permanent and semi-permanent wetlands in Gunbower forest is shifting (e.g. minor biodiversity loss, weed invasion) as a result of water stress arising from river regulation, recent drought and possible ground water extraction (Bennetts & Backstrom, 2009). Pollack Swamp wetlands and sites in the Gunbower red gum and black box woodlands were all found to be in moderate to poor condition with significant biodiversity losses and considerable weed invasions recorded (Bennetts & Backstrom, 2009). River red gum woodland with a flood dependent understorey has exhibited the greatest decline in condition during this monitoring period (Bennetts & Backstrom, 2009).

Key issues associated with floodplain understorey and aquatic vegetation

Major issues associated with understorey and aquatic vegetation in this Icon Site include the establishment and spread of weeds, including *Echium plantagineum* (Pattersons's curse), *Asparagus asparagoides* (bridal creeper), *Myriophyllum aquaticum* (parrot's feather), *Phyla canescens* (lippia) and *Genista* spp. (broom), and the loss of local biodiversity as a result of water stress. It is also likely that a streamward encroachment of flood dependent by flood tolerant understorey species has occurred as a result of decreasing flood frequency (Cooling *et al.*, 2002). Establishment of red gum seedlings in permanent and semi-permanent wetlands, similar to that occurring in the grass plains of Barmah Forest, has also been observed (Bennetts & Backstrom, 2008).

2.3 Hattah Lakes

Site description

The Hattah Lakes Icon Site is a large floodplain wetland system about 15 km from the River Murray between Ouyen and Mildura (MDBC, 2005a). The wetland system encompasses a wide range of aquatic and floodplain habitats including 18 shallow lakes, streams, temporary streams and riverine forest and is fed mostly by Chalka Creek which is connected to the River Murray. The site comprises two adjacent national parks, Hattah–Kulkyne National Park and Murray–Kulkyne National Park, with a combined area of 49,500 ha. Twelve of the eighteen lakes are listed under the Ramsar convention (MDBC, 2005a).

Ecological objectives relevant to understorey and aquatic vegetation

The interim ecological objectives and expected outcomes set by the Murray–Darling Basin Ministerial Council for the Hattah Lakes Icon Site (MDBC, 2006c) are:

i. restore healthy examples of all original wetland and floodplain communities

ii. restore the aquatic vegetation zone in and around at least 50% of the lakes to increase fish and bird breeding and survival

iii. increase the successful breeding events of colonial waterbirds to at least 2 years in 10

iv. increase the population size and breeding events of Murray hardyhead, Australian smelt, gudgeons and other wetland fish.

A further suite of ecological objectives have been developed by the Mallee CMA and The Living Murray for the use of environmental water (MDBC, 2005a). Of these the following are relevant to understorey and aquatic vegetation:

i. restore a mosaic of hydrological regimes which represent pre-regulation conditions (to maximise biodiversity)

ii. maintain, and where practical, restore the ecological character of the Ramsar site with reference to the Strategic Management Plan

iii. restore the macrophyte zone around at least 50% of the lakes (to increase fish and bird habitat)

iv. improve the quality and extent of deep freshwater meadow and permanent open freshwater wetlands so that species typical of these ecosystems are represented.

Floodplain understorey and aquatic vegetation

Lake beds within the Hattah Lakes Icon Site are typically dominated by herbfield species including *Glycyrrhiza acanthocarpa* (southern liquorice), *Centipeda* spp. (sneezeweed) and *Alternanthera denticulata* (lesser joyweed) (DSE, 2003 in MDBC, 2005a) but fluctuate between flood responsive and terrestrial species depending on hydrological conditions (McCarthy *et al.*, 2009). River red gum open woodlands are generally restricted to lower floodplain elevations around the lakes with black box woodland with an understorey of chenopod shrubs occupying higher elevations. Lignum shrubland, with clumps up to 3 m in height, also occurs around some of the lakes. Rat's tail couch grassland is another significant wetland plant community occurring within the Icon Site (MDBC, 2005a).

As part of the development of the Murray Flows Assessment Tool (MFAT), Treadwell (2003 in MDBC, 2005a) identified five wetland vegetation classes in the Hattah Lakes Icon Site; cumbungi, Phragmites, Moira grass grassland, giant rush rushland and ribbonweed herbland; and five floodplain vegetation classes; river red gum forest, river red gum woodland, black box woodland, lignum shrubland and rat's tail couch grassland. Ecological Vegetation Classes mapping has also been conducted across the Hattah Lakes although floristic summaries are not readily available (MDBC, 2005a).

Key understorey and aquatic taxa

Eleocharis acuta (common spike-rush)

Eragrostis australasica (cane grass)

Glycyrrhiza acanthocarpa (southern liquorice)

Juncus ingens (giant rush)

Muehlenbeckia florulenta (tangled lignum)

Myriophyllum spp. (milfoil)

Paspalum distchum (water couch)

Phragmites australis (common reed)

Pseudoraphis spinescens (Moira grass, spiny mud grass)

Spororbolus mitchellii (rat's tail couch)

Vallisneria americana var. americana (ribbonweed)

Condition of floodplain understorey and aquatic vegetation

Monitoring of understorey and aquatic vegetation condition in the Hattah Lakes Icon Site commenced in 2007 by the Murray Darling Freshwater Research Centre (McCarthy *et al.*, 2008). Consequently, the emphasis of monitoring to date has been establishing baseline data and describing spatial trends. While lake beds currently support a range of plant communities depending on their recent flood history, flood responsive species are conspicuously absent from the understorey of woodland communities, even in 'often' flooded areas as a result of up to 12 years since the occurrence of overbank flooding. Lignum at the site is considered to be in reasonable condition (McCarthy *et al.*, 2008).

Key issues associated with floodplain understorey and aquatic vegetation

As in the Barmah and Gunbower icon sites, loss of flood responsive species from the vegetation in response to dry conditions is a major concern in the Hattah Lakes Icon Site and drought tolerant species, e.g. chenopod shrubs, are encroaching vegetation communities at lower elevations (McCarthy *et al.*, 2008). There is also limited potential for the spread of cumbungi in the Icon Site (McCarthy *et al.*, 2008).

2.4 Chowilla Floodplain and Lindsay–Wallpolla Islands

Site description

This Icon Site encompasses three locations; Lindsay Island and Wallpolla Island in Victoria and the Chowilla Floodplain which spreads across the South Australia and New South Wales border. Lindsay and Wallpolla Islands occur on the southern side of the River Murray downstream of Mildura–Wentworth and are created by a series of anabranches. The Chowilla Floodplain is on northern side of the River Murray, mainly in South Australia. The Icon Site covers about 17,700 ha and comprises the largest floodplain complex in the lower Murray system (MDBC, 2005a).

Ecological objectives relevant to understorey and aquatic vegetation

Three broad ecological objectives were developed by The Living Murray Initiative First Step Decision in order to maintain biodiversity values of the Chowilla Floodplain (MDBC, 2006d):

i. high value wetlands maintained

ii. current area of river red gum maintained

iii. at least 20% of the original area of black box vegetation maintained

Specific objectives identified for the Chowilla Floodplain (MDBC, 2006d) also include 'to maintain and, where possible, enhance the health and conservation value of Chowilla by maintaining or improving:

i. the condition of existing vegetation, particularly vegetation currently classified as healthy or moderately health

ii. key aquatic, riparian and terrestrial habitats required by native flora and fauna

General objectives directly relevant to understorey and aquatic vegetation have also been developed for the Lindsay–Wallpolla Islands (MDBC, 2006d):

i. provide a diversity of structural aquatic habitats

ii. increase diversity and abundance of wetland aquatic vegetation

iii. maintain and improve the populations of threatened flora and fauna that are flow dependent.

Specific ecological objectives for water management in Lindsay–Wallpolla Islands, similar to those identified for Gunbower Forest, have also been developed for key wetland and vegetation communities (MDBC, 2006d):

i. *Permanent wetlands*: restore habitat and community diversity

ii. *Semi-permanent wetlands*: restore habitat and community diversity

iii. *Ephemeral wetlands* restore habitat and community diversity. Re-instate the communities typical of ephemeral wetlands

iv. *Lignum*: improve condition and increase extent to sustain species assemblages and processes typical of lignum communities

v. *Open grassland*: maintain habitat values and flora and fauna communities

vi. *River red gum*: maintain current condition and extent of river red gum communities to sustain species assemblages and processes typical of such woodland

vii. *Black box*: improve condition to sustain species assemblages and processes typical of black box woodland.

Floodplain understorey and aquatic vegetation

Black box woodland is the dominant vegetation type on the Chowilla floodplain and occupies almost 30% of its area (MDBC, 2006d). Permanent channels and wetlands may support a variety of submerged and emergent aquatic species and giant rush rushlands occur in low-lying areas. Red gum forest and woodland occupy intermediately flooded parts of the floodplain. Other wetland and floodplain communities present include lignum shrubland, *Acacia stenophylla* (river cooba) shrubland, rat's tail couch grassland, ribbonweed herbland and cane grass grassland (MDBC, 2005a, 2006d). Lindsay Island comprises a series of lignum swamps connected by streams fringed by river red gum communities (MDBC, 2006d). Black box woodland with an understorey of chenopod shrubs, including *Atriplex nummularia* (old man saltbush), occurs on the less frequently flooded parts of the floodplain and treeless chenopod shrublands occupy the highest floodplain areas (MDBC, 2006d). Wallpolla Island supports three major vegetation types; i) river red gum forest, ii) black box woodland with an understorey of chenopod shrubs, including old man saltbush, and iii) rat's tail couch grassland (MDBC, 2006d).

A number of vegetation classification and mapping schemes have been developed for the Chowilla Floodplain (in MDBC, 2005a; Marsland *et al.*, 2009) including:

i. O'Malley (1990): five floristic wetland and floodplain groups based on compositional similarities; floodplain black box (probably including river red gum, lignum and river cooba), lake-bed herbfield, river red gum forest, weedy lagoon and aquatic herbfield

ii. Sharely and Huggan (1995): classes based on Margules and Partners *et al.* (1990) mapping of vegetation communities along the River Murray

iii. Overton and Jolly (2003): mapping also based on Margules and Partners *et al.* (1990).

MFAT classification of floodplain vegetation identified four major communities; red gum woodland, black box woodland, lignum shrubland and rat's tail couch grassland; and also ribbonweed herbfield as a wetland vegetation class (MDBC, 2005a).

Key understorey and aquatic taxa

Eragrostis australasica (cane grass)

Juncus ingens (giant rush)

Muehlenbeckia florulenta (tangled lignum)

Phragmites australis (common reed)

Pseudoraphis spinescens (Moira grass, spiny mud grass)

Spororbolus mitchellii (rat's tail couch)

Typha spp. (cumbungi)

Vallisneria americana var. americana (ribbonweed)

Condition of floodplain understorey and aquatic vegetation

Vegetation in the Chowilla Floodplain was monitored between 2006 and 2008 by Marsland *et al.* (2009). During this period, a general shift in communities dominated by desiccation tolerant species to dominance by salt tolerant species, e.g. *Carpobrutus* sp. and *Pachycornia triandra*, has been observed. Wetland and terrestrial vegetation communities in the Lindsay–Wallpolla Islands have also been monitored by Henderson *et al.* (2008) who observed a low diversity and cover of flood responsive species in sites that were historically frequently inundated. Declining condition in lignum communities and expansion of cumbungi have also been detected (Henderson *et al.*, 2008).

Key issues associated with floodplain understorey and aquatic vegetation

The major issues associated with understorey and aquatic vegetation in this Icon Site involve the replacement of flood tolerant species by drought tolerant species, e.g. chenopod shrubs, and the replacement, in turn, of these by salt tolerant species (Marsland *et al.*, 2009; Nicol *et al.*, 2009). Displacement of aquatic macrophytes through the expansion of cumbungi stands is also of concern, particularly in the Lindsay–Wallpolla Islands where the number and length of stands have increased substantially since 2006 (Henderson *et al.*, 2008). Significant spread of exotic weed species, however, has not been observed in the Chowilla floodplain since 2006 despite the increased abundance of several species following environmental watering between 2004 and 2006 (Marsland *et al.*, 2009; Nicol *et al.*, 2009).

2.5 Lower Lakes, Coorong and Murray Mouth

Site description

The Lower Lakes, Coorong and Murray Mouth (LLCMM) Icon Site is a complex system of lakes and lagoons located in the lower freshwater reaches and estuary of the Murray River in South Australia. The Lower Lakes are Lake Alexandrina (76,000 ha) and Lake Albert (16,800 ha), which together form the largest freshwater body in South Australia (DEH, 2000). Lake Albert is connected to the southern end of Lake Alexandrina by the Narrung Narrows but does not have a direct connection with the Coorong or Murray Mouth. The Murray enters the LLCMM from the eastern side of Lake Alexandrina and exits through five channels (now controlled by barrages) that direct flow into the Coorong or the Murray Mouth (Lamontagne *et al.*, 2004). The Coorong is a 100 km long coastal lagoon separated from the southern ocean by a narrow coastal dune system (MDBC, 2005a). The Coorong can be divided into three sections based on salinity: the Murray estuary and the northern and southern lagoons. Salinity increases from the Murray estuary (estuarine) to the southern lagoon of the Coorong, which is hypersaline (MDBC, 2006e). The Murray Mouth is a relatively narrow tidal inlet but historically the size and location of the Murray Mouth was highly variable (Newman, 2000). The location, size and shape of the mouth are dictated by inflows from the Murray, tidal flows and coastal and oceanic processes (Harvey, 2002).

A wide variety of habitat types would have occurred in the LLCMM prior to flow regulation (i.e. reduced inflows and barrage construction) as a result of the salinity gradient created by freshwater inflows from the River Murray and tidal/oceanic processes and the diverse geomorphology of the region (Ganf, 2002; MDBC, 2005a). Salinity would have varied temporally in relation to seasonal variations in river discharge and tidal influence (Newman 2000). The Lower Lakes would have been predominantly freshwater due to inflows from the Murray (Walker, 2002; MDBC, 2006e) but saltwater intrusions may have occurred infrequently during periods of low flow (Sim & Muller, 2004). Historically Lake Albert may have been more saline than Lake Alexandrina due to a lack of freshwater inflow (Phillips and Muller, 2006). The Coorong would have varied from brackish water in the upper Coorong to hypersaline in the southern Coorong lagoon (MDBC, 2006e). Despite the substantial loss of estuarine habitat the LLCMM still supports a wide variety of wetland habitats (DEH, 2000; MDBC, 2006e).

Ecological objectives relevant to understorey and aquatic vegetation

The Living Murray initiative has identified the overall objective for the Lower Lakes, Coorong and Murray Mouth Icon Site as "A healthier Lower Lakes and Coorong estuarine environment" (MDBC, 2006e). Three sub-objectives have been identified to better describe the desired outcomes for this Icon Site (MDBC, 2006e). These sub-objectives are:

i. An open Murray Mouth
ii. More frequent estuarine fish spawning and recruitment
iii. Enhanced migratory wader bird habitat in the Lower Lakes and Coorong.

The Environmental Management Plan for the LLCMM has ecological targets that identify species and actions required to meet the ecological objectives. The targets associated with aquatic vegetation are:

i. enhanced *Ruppia megacarpa* colonisation and reproduction in the Coorong north lagoon
ii. enhanced *Ruppia tuberosa* colonisation and reproduction in the Coorong southern lagoon
iii. enhance mudflat exposure during summer in the Coorong and Lower Lakes
iv. maintain aquatic and floodplain vegetation in the Lower Lakes.

The Living Murray objectives are not the only management objectives developed for this Icon Site. Several government agencies and organisations have developed management objectives for the LLCMM (see DEH, 2000; Lamontagne *et al.*, 2004; MDBC, 2005b). This reflects the ecological, economic and social importance of this Icon Site.

Floodplain understorey and aquatic vegetation

The aquatic flora of the LLCMM prior to barrage construction is unknown (MDBC, 2005a) but has been inferred from current species distributions and known salinity tolerances (Ganf, 2000, 2002). It is evident that prior to barrage construction the variations in physical habitat and salinity would have supported a diverse aquatic flora. Historically, the aquatic vegetation of the Lower Lakes and Coorong would have been dominated by vegetation tolerant of saline surface waters and high root zone salinity (Ganf, 2000). The timing and duration of low flow periods may have been critical for the growth and reproduction of species on mudflats (Ganf, 2002).

The present day species composition and distribution of the aquatic flora is still indicative of salinity gradients present in the system (Ganf, 2002). Saline permanent waters are dominated by *Ruppia* spp., *Lepilaena* and the stonewort *Lamprothamnium papulosum*, while saline areas not permanently inundated are dominated by *Sarcocornia quinqueflora*, *Halosarcia* spp., *Wilsonia* spp., *Suadea australis*, *Silliera radicans* and Chenopodiaceae (Ganf, 2002). Freshwater habitats upstream of the barrages are dominated by the emergent macrophytes *Typha* spp., *Phragmites australis*, *Bolboschoenus caldwelli* and *B. medianus* that may form extensive monospecific stands. A diverse submerged and floating flora is present, including duckweeds, stoneworts, charophytes, *Triglochin striatum*, *T. procerum*, *Utricularia* spp., *Vallisneria americana*, *Ceratophyllum demersum*, *Myriophyllum* spp., *Villarsia reniformis*, *Ottelia ovalifolia*, and *Potamogeton tricarinatus* (Ganf, 2000; MDBC, 2006e; Walter & Souter, 2009). Opportunistic macroalgal species (*Enteromorpha*, *Rhizoclonium*) occur in subtidal saltwater habitats (Ganf, 2002).

Key understorey and aquatic taxa

Halosarcia sp. (samphire)

Lamprothamnium papulosum (foxtail stonewort)

Lepilaena spp. (water mat)

Phragmites australis (common reed)

Ruppia megacarpa (large fruit tassel)

Ruppia polycarpa (many-fruit tassel)

Ruppia tuberosa (tuberous tassel)

Zostera muelleri (eelgrass)

Heterozostera tasmanica (seagrass)

Sarcocornia quinqueflora (samphire)

Selliera radicans (swamp weed)

Suadea australis (Austral seablite)

Triglochin spp. (water ribbons)

Typha spp. (cumbungi)

Vallisneria americana var. americana (ribbonweed)

Villarsia reniformis (yellow marsh flower)

Wilsonia sp. (Wilsonia)

Condition of floodplain understorey and aquatic vegetation

It is recognised that the ecological condition of the LLCMM has declined (MDBC, 2005b). Plant biodiversity has been reduced through changes to flow regime, water levels, turbidity and salinity (Ganf, 2002). Prior to flow regulation much of the plant biodiversity would have been associated with floodplains and temporary wetlands, rather than with the main channel (Ganf, 2000). The submerged flora of the Lower Lakes is now restricted to inshore areas due to increased turbidity but may have been previously more widespread throughout the lakes (Ganf, 2000).

Condition monitoring in relation to the targets set for the ecological objectives indicate that *Ruppia megacarpa* has disappeared from the north lagoon, and the *R. megacarpa* seed bank was found to have very low viability (MDBC, 2008). Similarly, *R. tuberosa* had disappeared from the south lagoon (MDBC, 2008). Clearly, targets for *R. megacarpa* and *R. tuberosa* (i.e. enhanced colonisation and reproduction) have not been met. Insufficient information was available to determine whether the target related to maintenance of floodplain and aquatic vegetation had been met (MDBC, 2008).

Key issues associated with floodplain understorey and aquatic vegetation

Several issues are of importance to the aquatic vegetation of this Icon Site (Ganf, 2000). Flow regulation (reduced inflows into Lake Alexandrina from the Murray and barrage construction in the estuary) has substantially altered the salinity gradient and habitat availability (Newman, 2000). The natural (pre-regulation) discharge regime of the Murray River (including the lower freshwater reaches) was characterised by high discharge variability (Newman, 2000). Seasonal discharge variations would have produced seasonal changes in salinity gradients but these changes are now more rapid (Jensen *et al.*, 2000). Under natural conditions peak monthly flow (100 GL per annum) occurred in mid-late spring but under current conditions peak monthly flow (600 GL per annum) occurs in late winter-early spring (Newman, 2000). Prior to flow regulation river discharge would have been sufficient to maintain an open river mouth in most years (Newman, 2000). The five barrages in the Coorong effectively shorten the salinity gradient since brackish water (estuarine) habitats have been substantially reduced in areal extent by approximately 90% (Newman, 2000). The Coorong would have received more freshwater inputs from Lake Alexandrina prior to barrage construction (now reduced to less than 30% of natural inflows) but the hypersaline conditions in the southern lagoon are probably representative of past conditions (Newman, 2000). The pre-European salinity levels of the Coorong are uncertain but it is thought that current salinity levels are higher than natural (MDBC, 2006e). Newman (2000) summarised the primary change for the lower River Murray following flow regulation as the loss of the "vast estuarine system" and subsequent loss of biodiversity.

The barrages maintain water levels at a higher and more static level than naturally existed (Newman, 2000; Webster, 2007). The aim of barrage management is to maintain relatively static water levels but sudden increases in water depth are possible due to wind fetch (Ganf, 2000). Sudden changes in water level may cause plant mortality through desiccation or inundation (no access to atmospheric CO_2 for emergent taxa and/or reduced light availability) (Ganf, 2000). During periods of low flow the barrages may remain closed for many months (Newman, 2000). Webster (2007) states that flows from the gates are often zero. Flow regulation of the Murray as well as barrage construction have increased the tendency of the Murray Mouth to close, which can increase salinity and sedimentation in the Coorong (Newman, 2000; Webster, 2005).

2.6 River Murray Channel

Site description

The River Murray Channel stretches 2,225 km from the Hume Dam, near Albury, to its mouth in South Australia into the Southern Ocean. The Channel comprises five broad reaches defined on the basis of control structures and proximity to major tributary confluences: the headwaters, the riverine plains, the mallee trench, the mallee gorge and the lower lakes and Coorong. The lateral extent of this Icon Site includes the physical River Murray channel, i.e. river bed, banks and the direct riparian zone, as well as anabranches and riverine wetlands, e.g. billabongs, not encompassed by the other icon sites that are affected by regulated flows or can be opportunistically managed in delivering outcomes at other icon sites (MDBC, 2006f). Ten 3m high weirs occur on the lower River Murray between Wentworth and Blanchetown forming pools ranging between 29 and 88 km in length (Blanch *et al.*, 1999).

Ecological objectives relevant to understorey and aquatic vegetation

The interim ecological objectives and expected outcomes set by the Murray–Darling Basin Ministerial Council First Step Decision for The Living Murray for the River Murray Channel Icon Site are:

i. increase the frequency of higher flows in Spring, that are ecologically significant

ii. overcome barriers to migration of native fish species between the sea and Hume Dam

iii. maintain current levels of channel stability (MDBC, 2006f).

A further suite of objectives relevant to understorey and aquatic vegetation for this Icon Site were also agreed to by the Murray–Darling Basin Ministerial Council in 2001 (MDBC, 2006f):

i. protect and restore key habitat features in the river and riparian zone

ii. prevent the extinction of native species from the riverine system

iii. reinstate ecologically significant elements of the natural flow regime (including seasonal flow variability)

iv. where possible, improve connectivity between the river and riparian zone to facilitate wetting and drying

v. manage flow-related water quality to a level that sustains ecological processes and productive capacity

vi. recognise the importance of maintaining a healthy and productive River Murray to the social, economic, cultural, environmental and other values along the river

vii. ensure that actions under this plan do no significantly threaten these values.

Floodplain understorey and aquatic vegetation

Margules *et al.* (1990) identified 37 plant communities from the riparian zone of the River Murray which could be classified into four vegetation types dominated either by river red-gum or black-box. Salinity was a key driver in separating the four community types, with a riverine plains community type (dominated by river red gum) associated with relatively low salinity. The riverine plains community was dominated by *Paspalidium jubiflorum*, *Pseudoraphis spinescens*, *Eleocharis acuta*, *Cyperus gymnocaulos*, *Centipeda cunninghamii*, *Senecio quadridentatus* and *Wahlenbergia fluminalis*. Variations in elevation that influence the frequency and duration of flooding at fine spatial scales were an important driver of species composition across the floodplain (Margules *et al.*, 1990; see also Blanch *et al.*, 1999).

Weir pools in the lower River Murray support littoral vegetation including emergents such as cumbungi, ribbonweed, milfoil, *Cyperus* spp. and Warrego summer grass (Blanch *et al.*, 1999, 2000). In water ponding areas on floodplain adjacent to the channel, communities may be dominated by spike-rushes of Moria grass (Blanch *et al.*, 1999). Lignum shrubland and rat's tail couch grassland also occur on the floodplain (Blanch *et al.*, 1999). Riparian vegetation along the River Murray typically comprises river red gum communities sometimes with a reed-bed understorey (Roberts & Ludwig, 1991).

Key understorey and aquatic taxa

Bolboschoenus medianus (marsh club rush)

Cyperus gymnocaulos (spiny sedge)

Eleocharis acuta (common spike-rush)

Muehlenbeckia florulenta (tangled lignum)

Phragmites australis (common reed)

Pseudoraphis spinescens (Moira grass, spiny mud grass)

Paspalidium jubiflorum (Warrego summer grass)

Spororbolus mitchellii (rat's tail couch)

Typha spp. (cumbungi)

Vallisneria americana var. americana (ribbonweed)

Wahlenbergia fluminalis (river bluebell)

Condition of floodplain understorey and aquatic vegetation

The condition of riparian and aquatic vegetation communities in the River Murray is declining. Margules *et al.* (1990) rated the condition of riparian vegetation as poor, although condition varied between river sections. Norris *et al.* (2001) rated riparian vegetation condition as poor along the entire length of the Murray channel. The 2008 Icon Site condition assessment (MDBC, 2008) did not address vegetation condition.

Historical evidence suggests that macrophyte diversity and abundance in billabongs of the River Murray declined sharply between the late 1800s and 1930, probably as a result of catchment development (Ogden, 2000). Research suggests that submerged macrophytes have been the most affected and macrophyte beds in large, deep (> 1.5 m mean annual depth) billabongs the most degraded (Ogden, 2000).

Several submerged and aquatic species have apparently disappeared from the South Australian reach of the Murray channel but are still common upstream (Margules *et al.*, 1990). These include *Damasonium minus*, *Eleocharis pusilla*, *Najas tenuifolia*, *Nymphoides crenata* and *Pseudoraphis spinescens*. These species were classified as threatened in South Australia (Margules *et al.*, 1990) but of these species only *Najas tenuifolia* and *N. crenata* remain classified as rare or threatened (South Australian Government, 2008).

Key issues associated with floodplain understorey and aquatic vegetation

A variety of factors influence the condition of the vegetation in the River Murray channel, and these may vary from reach to reach (MDBC, 2006). These include the substantial changes to the natural flow regime induced by dams and weirs (particularly flow stabilisation, unseasonal flooding, and prolonged periods of low flow), water quality (salinity, turbidity), riparian and in-stream habitat management and habitat management of alien species (MDBC, 2006f). These factors are associated with the local extirpation of flood dependent and flood tolerant species and the increased spread of exotic species, as has been found for other icon sites. Margules *et al.* (1990) rated weed infestation as the most widespread form of riparian vegetation degradation in the River Murray. Approximately one third of the flora on the floodplain is introduced (Margules *et al.*, 1990). While the proportion of weeds in floodplain communities varied the proportion of weeds was lower in semi-arid areas and was also lower in areas subjected to regular flooding (Margules *et al.*, 1990). Flow regime changes and salinity are also key factors influencing the condition of riparian and floodplain vegetation (Margules *et al.* 1990; Gehrke *et al.*, 2003).

3. Effects of flooding on floodplain understorey and aquatic plant habitat

3.1 Overview

Flooding and drying have an overriding influence on the characteristics of plant habitats in riverine landscapes, i.e. resource availability and the presence and intensity of stressors, as well as temporal and spatial patterns in these (Gregory *et al.*, 1991; Blom *et al.*, 1994; Naiman & Décamps, 1997; Stromberg, 2001; Brock *et al.*, 2006). Flooding can be perceived of as a 'pulse' disturbance, comprising discrete, short-term events in which riverine habitat characteristics shift along a 'hump' while drying is a 'ramp' disturbance in which the intensity of habitat alterations gradually increase over time (Fisher *et al.*, 1982; Lake, 2000).

3.2 Resource availability

Soil moisture and nutrient content are often higher in riverine habitats than in adjacent upland habitats and vegetation production may benefit as a result (Megonigal *et al.*, 1997). Flooding, however, causes considerable temporal shifts in the availability of critical plant resources and these are also likely to vary spatially between different habitat types, e.g. channels, floodplains, lakes etc., as a result of variations in hydrology and geomorphology (Brock *et al.*, 2006). During flooding, water and nutrient availability increase but the bioavailability of plant resources may be reduced by changes to soil, including anoxia, the accumulation of toxic materials and soil compaction, as well as reductions in light availability and alterations in temperature (Blom & Voesenek, 1996). Light availability will be influenced by flood depth and can also be affected by changes in turbidity associated with flooding. In the River Murray, water, light and atmospheric gas availability are thought to be optimal in shallow water of less than 20 cm depth (Blanch *et al.*, 1999).

Flooding can also result in the creation of new areas of bare substrate suitable for colonisation by plants and, over longer time periods, may cause changes in habitat availability at a landscape scale by altering habitat morphology, e.g. formation of ox-box lakes (Stromberg, 2001). Furthermore, an additional vector for seed dispersal, hydrochory, is provided by floodwaters (Nilsson *et al.*, 1991).

In contrast, drying restricts the availability of soil moisture in riparian and floodplain habitats (Blanch *et al.*, 1999) and reduces connectivity between habitats, thus restricting propagule dispersal (Brock *et al.*, 2006). In aquatic habitats, water quality changes may also occur as water levels drop, e.g. increasing salinity resulting from evapotranspiraton and increasing turbidity due to the mobilisation of lakebed sediments by wind and wave action (EPA and MDFRC, 2008). Periods of drying, however, also allow changes in propagule dormancy to occur (Baskin & Baskin, 1998) and may facilitate the release of sediment bound nutrients (Baldwin & Mitchell, 2000).

3.3 Stress and disturbance

Considerable stress to plant metabolism is imposed on plants by soil anoxia and the accumulation of toxic ions, e.g. iron and manganese, in the soil that result from flooding (Blom & Voesenek, 1996). Flooding can also lead to mechanical disturbance to plants as a result of wave action or fast flows (Menges, 1986) and this may be particularly significant for plants adapted to slow flowing conditions or mud-mat and short submerged species (Blanch *et al.*,1999). The growth of plant roots can be stressed by soil compaction following flooding (Blom & Voesenek, 1996) and the germination and growth of seedlings can be impeded by burial from sediments deposited during flooding (Sluis & Tandarich, 2004). Floods may also scour sediments in some habitats and consequently remove the viable soil seed bank concentrated in the upper sediment layers (James *et al.*, 2007).

Drying will reduce the area and quality of aquatic habitats and exposure may result in mortality in desiccation intolerant plants (Blanch *et al.*,1999). Declining soil moisture availability is also likely to cause significant stress in the majority of riparian and floodplain plants. Increasing salinity resulting from the evapoconcentration of salts can also result from drying causing stress to salt-intolerant plants (Boulton & Brock, 1999).

3.4 Temporal and spatial dynamics

Riverine plant habitats are typically highly heterogeneous, both temporally and spatially, due to complex interactions between surface water hydrology and geomorphology (Stromberg, 2001). Conceptually, riverine plant habitats can be perceived of as 'patch mosaics' comprising dynamic patches of varying physical, chemical and biotic character (Pickett & White, 1986). The intensity and scale of temporal shifts in plant habitat character resulting from flooding or drying are dependent on hydrological attributes including flood timing, magnitude, duration and frequency (Brock *et al.*, 2006). Flood magnitude, for instance, will influence the extent of plant habitat affected by changes as well as the intensity of impacts, e.g. light availability will be influenced by water depth. Similarly, rates of floodwater rise and fall may influence the potential for mechanical damage to plant stems. Due to differences in patterns of flooding and drying over the longer-term, plant habitats also vary spatially amongst different geomorphic habitats (Brock *et al.*, 2006; James *et al.*, 2007).

4. Effects of flooding on floodplain understorey and aquatic plants

4.1 Overview

Understorey and aquatic plants inhabiting riverine habitats exhibit a wide range of traits that enable their persistence through periods of flooding and drying (Brock *et al..,* 2006). Plants may possess morphological traits or physiological mechanisms that enable tolerance of the stressors associated with flooding or drying (or both) or may display life history patterns that enable their avoidance of unfavourable conditions and the ability to recolonise and establish when conditions are appropriate (Brock *et al.*, 2006). Flooding has the potential to interact with every stage of a plant's life history and the outcomes of these interactions will have a major influence on the presence, abundance and condition of plant species in a riverine habitat at any particular time.

4.2 Growth

The growth and survival of floodplain understorey and aquatic plants is determined through interactions between hydrological conditions and plant morphological and physiological traits. Plant age can also play a role since plant traits vary with age (Capon *et al.*, 2009). Most terrestrial plants are intolerant of submergence or waterlogging and will consequently senesce and die in response to flooding. Many shrubs and sub-shrubs, including some chenopods and *Acacia* spp., are amongst this category (Pettit *et al.*, 2001; Capon, 2003). Other shrubs, e.g. lignum and river cooba, however are able to tolerate considerable durations of inundation although growth is likely to be favoured by damp conditions following floodwater recession (Capon *et al.*, 2009). Submergence may trigger growth in submerged and amphibious species but many forb, grass and monocot species are likely to favour waterlogged or damp conditions. Some amphibious species, e.g. Moira grass and milfoil, may alter their growth form between submerged and waterlogged phases (Roberts & Marston, 2000).

Water depth will be an important factor influencing the growth of individual species as well as competitive interactions between these (Roberts & Marston, 2000). Some species, e.g. cumbungi, favour stable water levels, while other species, e.g. common reed, can tolerate fluctuating water levels (Roberts & Marston, 2000). Flood timing may also influence growth rates in some plants (Ward, 1991; Nicol & Ganf, 2000) and the duration of flooding will determine the amount of growth that occurs and, in some species, the ability to produce underground storage organs (Roberts & Marston, 2000).

The duration of drying periods intervening flood events will also affect growth responses of floodplain understorey and aquatic plants. Some species, e.g. submerged and some amphibious plants, are dessication intolerant and will consequently senesce and die in response to drying (Blanch *et al.*, 1999). Other floodplain plants exhibit considerable drought tolerance. Lignum shrubs, for example, can persist for extended periods (several years) as leafless photosynthetic stems that respond rapidly to rainfall or flooding (Roberts & Marston, 2000).

Table 1 provides a summary of growth characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites and the influence of flooding on these.

4.3 Vegetative reproduction

Many aquatic plants and some dominant perennial emergents, e.g. giant rush and common reed, spread mainly via vegetative growth and asexual reproduction is typically the major mode of plant regeneration and spread in wetlands (Cronk & Fennessy, 2001). Vegetative reproduction may occur via modified stems, e.g. stolons and rhizomes, modified roots, e.g. tubers, or as a result of the dispersal of plant fragments or modified buds, e.g. turions (Cronk & Fennessy, 2001). In submerged and floating plants, e.g. milfoil, the dispersal of shoot fragments and subsequent generation of new individuals from these is one of the principle means of vegetative reproduction (Cronk & Fennessy, 2001). In other plants, arching stems develop adventitious roots on contact with soil (stem layering), e.g. lignum (Chong & Walker, 2005). Common reed expands via horizontally growing stems (stolons) which can grow as long as 13 m (Cronk & Fennessy, 2001).

Flooding is likely to have a strong influence on rates and types of vegetative reproduction occurring in floodplain understorey and aquatic plants since these will be closely related to plant growth. In some species, plants may vary their allocation to asexual or sexual reproduction according to hydrological conditions. Moira grass, for example, shifts from flowering and seed production during flooding to vegetative growth when the recession of floodwaters triggers stems to root at nodes (Ward, 1992). Similarly, some *Typha* spp. rely on seed to colonise new sites but depend on rhizomes to expand into areas of deeper water (Cronk & Fennessy, 2001). The duration of dry periods intervening floods will also affect the ability of plants to regenerate from vegetative propagules, e.g. tubers, fragments or buried rhizomes, as these will have limited longevity.

Table 2 provides a summary of vegetative reproduction characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites and the influence of flooding on these.

4.4 Sexual reproduction

Although asexual reproduction is typically the dominant mode of plant regeneration in wetlands (Cronk & Fennessy, 2001), sexual reproduction is more significant in some habitats and for some groups of plants. Generally, sexual reproduction is considered to be beneficial in heterogeneous and unpredictable environments (Cronk & Fennessy, 2001). Plant communities of temporary wetlands and dryland floodplains, for instance, tend to rely on sexual reproduction and persistent soil seed banks for recruitment (Brock *et al.*, 2006; Capon & Brock, 2006). Annual and ephemeral forbs and monocots will also depend on sexual reproduction for persistence. In some plants that mainly exhibit vegetative reproduction, sexual reproduction may represent an important means of colonising new habitats, e.g. common reed or *Typha* spp., or regenerating after major disturbances, e.g. regeneration of submerged plants from small persistent seed banks (Abernethy & Wilby, 1999).

Flooding has the potential to influence sexual reproduction via its affect on plant growth, as this may determine plant reproductive status, or directly as some hydrological attributes may trigger a reproductive response (Cronk & Fennessy, 2001). Water depth will be important as in most angiosperms, pollination and fertilisation occur in dry conditions and flowers therefore need contact with the air (Cronk & Fennessy, 2001). Flood timing may also influence flowering rates and seed production as season may determine plant age or size and subsequently, reproductive capacity.

Table 3 provides a summary of sexual reproduction characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites and the influence of flooding on these.

Table 1: Growth characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites
N.B. Only species for which information was identified during the current review are shown. Empty cells do not necessarily represent knowledge gaps but rather reflect a lack of information identified during the current review.

Taxa	Rates	Water depth	Timing	Flood duration	Flood frequency	Tolerance of drying
common reed	-	Can tolerate fluctuating water levels (Roberts & Marston, 2000). Growth favoured by shallow flooding (Ostendorp, 1991). Lower limit generally 1.5 – 2m but <60 cm on banks of River Murray in South Australia (Blanch *et al.*, 1999).	-	Long periods of submergence will cause mortality (Roberts & Marston, 2000). On lower River Murray, occurs where floods for 80–225 days.yr (Blanch *et al.*, 1999).	-	Can survive on groundwater (Ostendorp, 1991).
common spike-rush	-	<10 cm optimal in northern Victoria (Ward, 1996). Favours waterlogged over submerged conditions (Blanch & Brock, 1994).	Spring – summer optimal in northern Victoria (Ward, 1996).	Tolerates 3–10 months but 8 months of flooding optimal in northern Victoria (Ward, 1996).	-	-
cumbungi	Can grow to 1m with rhizome in few months (Nicol & Ganf, 2000)	Favoured by stable water regime, especially in early growing season Lower limits <2m deep (Ward, 1996; Roberts & Marston, 2000). In SA, grows on permanently wet or moist sites with < 20–60 cm depth (Blanch *et al.*, 1999).	Prefers warm conditions (Nicol & Ganf, 2000). Slow leaf growth in winter, rapid in spring and early summer, after mid-summer growth is below-ground with carbohydrate storage in rhizomes and shoots senesce. New shoots emerge in autumn-winter. (Roberts & Marston, 2000).	Favoured by wet spring and summer (Roberts & Marston, 2000). Tolerates 9-12 months with 11 months optimum in northern Victoria (Ward, 1996).	-	Tolerates 3-4months of drying in summer-autumn after growing season (Roberts & Marston, 2000).
giant rush	-	Can't tolerate deep flooding (Brix *et al.*, 1992). Up to 1.5m in northern Victoria (Ward, 1996).	-	In northern Victoria, occurs where winter-spring flooding lasts for 6-11 months. Optimum duration of 9 months (Ward, 1996).	-	-
lignum	-	-	-	Usually in areas flooded 2 - 4 months (Roberts & Marston, 2000). Killed by extended periods of submergence but duration unknown (Capon, 2003).	Best maintained by flooding every 3-10 years or more frequently where soils are saline (Craig *et al.*, 1991).	Tolerant of dry conditions for period of years but duration unknown.

Taxa	Rates	Water depth	Timing	Flood duration	Flood frequency	Tolerance of drying
milfoil	-	Adapted to fluctuating water levels. Changes morphology between submerged and moist conditions (Roberts & Marston, 2000).	-	-	-	-
Moira grass	Shoot extension of 10mm/ day (winter) – 20mm/day (late spring) in Barmah (Ward, 1991). Rapid growth after summer flooding in Chowilla with 2m long flowering shoots present 4-6 wks after flooding commenced (Roberts & Marston, 2000).	Minimum 0.5 m needed in Barmah to out-compete red gum seedlings (Ward, 1996). Can withstand up to 2m elsewhere in Victoria (Ward, 1996).	Summer flooding promotes more rapid growth. Continuous late winter-early spring flooding receding before summer is ideal in Barmah (Ward, 1992).	7-10 months of flooding throughout Victoria (Ward, 1996). Minimum flood duration of 5 months, but 7 preferable, to out-compete red gum seedlings in Barmah (Ward, 1996).	3 out of 4yrs in Barmah (Bren & Gibbs, 1986)	Longest inter-flood period in Barmah of 25 months (Bren, 1992).
rat's tail couch	-	Endures 20-60cm flooding along Murray channel (Blanch *et al.*, 1999).	-	Up to 73 days along Murray channel (Blanch *et al.*, 1999). Responded to 44 days flooding River Murray riparian zone but declined after 75 days. Critical duration appears to be 50-60 days of top-flooding. (Siebentritt *et al.*, 2004).	-	-
ribbonweed	Relative growth rate (RGR) over turbidity range of 90 – 504 NTU was 17.5 mg g-1 d-1 – 2.4 mg g-1 d-1 (Blanch *et al.*, 1998).	Shallow & deep conditions, depth determined by light penetration (i.e. turbidity) (Blanch *et al.*, 1998) Can be at 6m depth (Royle & King, 1991). Minimum depth of 1m as depth needs to enable leaf extension during growing season (Briggs & Maher, 1985).	Canopy initiated in spring, peaking late summer & dieback at start of winter (Briggs & Maher, 1985).	Long enough for completion of all phases including autumn build-up of underground storage (Roberts & Marston, 2000). Response to flooding dependent upon light attenuation (Blanch *et al.*, 1998).	-	Intolerant of exposure (Briggs & Maher, 1985; Blanch *et al.*, 1999). Cycles of drying and re-flooding was found to increase maximum standing crop (Briggs & Maher, 1985).

Taxa	Rates	Water depth	Timing	Flood duration	Flood frequency	Tolerance of drying
spiny sedge	-	Tolerates flooding up to 60 cm deep in South Australia (Blanch *et al.*, 1999). <10 cm optimal in northern Victoria (Ward, 1996).	Spring – summer optimal in northern Victoria (Ward, 1996).	Tolerates 80 -195 days in South Australia (Blanch *et al.*, 1999). Tolerates 2-6 moths with 3 months of flooding optimal in northern Victoria (Ward, 1996).	-	-
terete culm sedge	-	Tolerates flooding up to 10 cm deep in northern Victoria (Roberts & Marston, 2000).	Spring- summer flooding preferable in northern Victoria (Roberts & Marston, 2000).	Tolerates 1-4 months flooding in northern Victoria with 2 months optimal (Roberts & Marston, 2000).	-	-
large fruit tassel	-	-	-	-	-	Requires permanent water (Jacobs & Brock, 1982).
tuberous tassel	A "rapid" (annual) life cycle	-	Inundation required during autumn-winter (Jacobs & Brock, 1982).	-	-	High (a species of ephemeral habitats), remains dormant during dry season (Paton, 2005)
water couch	-	>10cm depth needed (Bennett & Green, 1993 in Roberts & Marston, 2000). On lower River Murray banks, occurs where depths <60cm (Blanch *et al.*, 1999).	Summer growing	4-8 weeks (Bennett & Green, 1993 in Roberts & Marston, 2000). On lower River Murray banks, occurs where floods for 150-220 days/yr (Blanch *et al.*, 1999).	Needs regular flooding. Once to twice a year & may tolerate repeated floods (Bennett & Green, 1993 in Roberts & Marston, 2000).	-
water primrose	-	<1 m deep in northern Victoria (Ward, 1996).	Winter-summer floods in northern Victoria (Ward, 1996).	8-10 months in northern Victoria (Ward, 1996).	-	-
water ribbons	-	0.5 m to 1.5 m in northern Victoria (Ward, 1996). Can tolerate fluctuating water levels, e.g. 0 – 50cm, 50 – 100 cm & 0 – 100 cm (Rea & Ganf, 1994)	Winter-summer floods in northern Victoria (Ward, 1996).	Tolerates 1-8 months, optimum duration of 6 months in northern Victoria (Ward, 1996).	-	I-
waxy marshwort	-	<1 m deep in northern Victoria (Ward, 1996).	Winter-summer floods in northern Victoria (Ward, 1996).	9-10 months in northern Victoria (Ward, 1996).	-	-

Table 2: Vegetative reproduction characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites

N.B. Only species for which information was identified during the current review are shown. Empty cells do not necessarily represent knowledge gaps but rather reflect a lack of information identified during the current review.

Taxa	Strategy	Prevalence of asexual reproduction	Flood triggers	Tolerance of drying
common reed	Rhizomes (Roberts & Marston, 2000) Stolons (Cronk & Fennessy, 2001)	High	-	Rhizome can survive up to a few years if protected at depth (>0.5m) in heavy clay (Roberts & Marston, 2000).
cumbungi	Rhizomes (Cronk & Fennessy, 2001)	High	-	-
lignum	Rhizomes Stem arching/ layering Fragments (*personal observations of authors*; Chong & Walker, 2005)	High	-	-
milfoil	Shoot fragments Turions (Cronk & Fennessy, 2001)	Dominant	-	-
Moira grass	Rhizomes Plant fragments can also establish in moist habitats (Roberts & Marston, 2000).	High	Flood recession causes stems to root at nodes promoting asexual reproduction (Ward, 1992).	-
rat's tail couch	Rhizomes	High	-	-
ribbonweed	Stolons Regrowth from tubers or fragments (Roberts & Marston, 2000) Turions (Cronk & Fennessy, 2001)	High (Jarvis & Moore, 2008)	-	
large fruit tassel	Vegetative spread by rhizomes (Jacobs & Brock, 1982). Perennating organs absent (Brock, 1982a). Rhizomes primary method of reproduction (Brock, 1982b).	Low. Rhizomes important for local spread (Jacobs & Brock, 1982).	-	No (Jacobs & Brock, 1982).
tuberous tassel	Rhizomes and turions (Jacobs & Brock, 1982).	High (Brock, 1982a).	-	High (Brock, 1982a,b) since it is an annual species of ephemeral habitats.
water couch	Rhizomes	-	-	Can survive a few years without flooding via buried rhizomes and nodes (Roberts & Marston, 2000).

Table 3: Sexual reproduction characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites

N.B. Only species for which information was identified during the current review are shown. Empty cells do not necessarily represent knowledge gaps but rather reflect a lack of information identified during the current review.

Taxa	Prevalence	Timing of flowering	Flood triggers
common reed	Some populations may rarely set seed despite vigorous flowering (Roberts & Marston, 2000). Many flowers may be sterile (Frankenberg, 1997).	Flowers from autumn to late summer in south-eastern Australia (Frankenberg, 1997; Roberts & Marston, 2000).	Seed set reduced under stressful (dry?) conditions (Roberts & Marston, 2000). Sterility varies spatially and temporally according to conditions (Frankenberg, 1997).
cumbungi	High seed production (few 1000 per inflorescence) (Roberts & Marston, 2000).	Flowers spring-summer (Roberts & Marston, 2000).	-
giant rush	Observations suggest great capacity to set seed under favourable conditions (Roberts, 2006 in Abel *et al.* 2001).	Spring (Ward, 1992)	Only flowers during flooding (Ward, 1992).
lignum	-	Flowers opportunistically in response to rainfall or flooding (Roberts & Marston, 2000).	-
Moira grass	-	Mainly mid-summer (Nov-Jan), approximately 1 month after stem apex has emerged from water, mostly on larger individuals (Ward, 1992).	Occurs during wet phase. Earlier flooding in Barmah (June rather than July) results in poor flowering rates. Continuous late winter/early spring for maximum reproductive potential. Minimum flood depth of 0.5m to prevent premature nodal rooting (Ward, 1992).
ribbonweed	Flowers throughout range but flowering frequency (as proportion of ramets or shoots that flowered) can be low (<5%, Lokker *et al.* (1997). Lokker reported flowering rates of 28-60%.	Plants must be several years old before flowering (Roberts & Marston, 2000). Flowers in summer (Catling *et al.*, 1994).	Only flowers when plant is submerged (Ward, 1994).
large fruit tassel	Seed bank important for this species. Germination may not occur in stable habitats conducive to where vegetative growth (Brock, 1982a).	November-March (Brock, 1982a).	No specific flood trigger but may require freshwater or dilution of saline waters (Brock, 1982a).
tuberous tassel	Seed set important for this species (Brock, 1982a).	August-November (Brock, 1982a); late spring-early summer (Paton, 2005).	Requires inundation in autumn-winter for germination.
water couch	-	Summer (Roberts & Marston, 2000)	-

4.5 Propagule dispersal

Propagule dispersal amongst floodplain understorey and aquatic plants is likely to occur primarily via wind, floodwaters or animal vectors. Understanding of plant propagule dispersal in Australian riverine systems, however, is extremely limited (Groves *et al.*, 2009) and represents a major knowledge gap.

Flooding can influence the dispersal of plant propagules via hydrochory and in some riverine habitats this is the dominant form of seed dispersal (Nilsson *et al.*, 1991). The seeds of many aquatic and floodplain plants are buoyant due to small seed size or hard seed coats containing gas spaces (Cronk & Fennessy, 2000) and these may be widely dispersed by floodwaters. Seeds of the common reed, for instance, float for 2 to 3 days (Coops & van der Velde, 1995) and those of lignum for 5 to 25 days (Chong & Walker, 2005). Seeds may also be distributed suspended in the water column or along the bottom of channels (Groves *et al.*, 2009). Some plants, e.g. ribbonweed, may disperse as plant fragments as well as seeds (Roberts & Marston, 2000). The amount and type of propagules dispersed by floodwaters will be influenced by flood timing, as this will determine the availability of propagules. Cumbungi seeds, for example, tend to be dispersed in late summer-early autumn (Roberts & Marston, 2000) while lignum seeds are dispersed opportunistically following rainfall or flood induced flowering events. The duration and magnitude of flooding will also affect the distribution of seeds and the rate of drawdown may determine when and where seeds are deposited.

Table 4 provides a summary of propagule dispersal characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites and the influence of flooding on these.

4.6 Propagule banks

Many aquatic and floodplain understorey plants, especially annual and short-lived perennial forbs and monocots, maintain abundant and persistent soil seed banks (Capon & Brock, 2006; James *et al.*, 2007; Williams *et al.*, 2008). Submerged, amphibious and terrestrial species can all have soil seed banks (Nicol *et al.*, 2003; Robertson & James, 2007). Tree and shrub species, however, tend to be poorly represented in wetland soil seed banks if present at all (Leck, 1989; Rossell & Wells, 1999; Schneider & Sharitz, 1986) and evidence indicates that lignum, the dominant shrub species in The Living Murray icon sites does not maintain persistent seed banks either (Chong & Walker, 2005). Seeds of *Juncus* spp. are often widespread and abundant in soil seed banks across a variety of wetland and terrestrial habitats (Bossuyt & Olivier, 2008), e.g. in riparian zones of lowland streams in south-eastern Australia (Williams *et al.*, 2008) as may be charophyte propagules (Porter *et al.*, 2007). Perennial hydrophytes, i.e. species that usually dominate open water habitats such as *Myriophyllum* spp. and *Potamogeton* spp., typically form relatively small persistent seed banks (Abernethy & Wilby, 1999). Moira grass is also known to maintain relatively small but persistent soil seed banks in floodplains of northern Australia (Finlayson *et al.*, 1990).

The duration of seed viability varies amongst species. Common reed seeds, for example, are known to retain viability for up to 3 to 4 years (Haslam, 1972) while many ephemeral forbs are likely to survive well over a decade and probably for much longer periods (Leck & Brock, 2000; Capon & Brock, 2006). The longevity of seeds in soil seed banks may be influenced by hydrology. The persistence of *Juncus* seeds, for example, are favoured by waterlogged conditions (Holzel & Otte, 2004) whilst giant rush seeds are thought not be able to survive extended periods of submergence (MDBC, 2005a).

Table 5 provides a summary of propagule bank characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites and the influence of flooding on these.

Table 4: Propagule dispersal characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites

N.B. Only species for which information was identified during the current review are shown. Empty cells do not necessarily represent knowledge gaps but rather reflect a lack of information identified during the current review.

Taxa	Timing of dispersal	Seed buoyancy	Wind dispersal	Animal dispersal	Dispersal of vegetative fragments
common reed	Seed ready for dispersal in autumn in south-eastern Australia (Roberts & Marston, 2000)	2-3 days (Coops & van der Velde, 1995)	-	-	-
cumbungi	Late summer – early autumn (Roberts & Marston, 2000).	-	Yes (Roberts & Marston, 2000)	-	-
lignum	-	5-25 days (Chong & Walker, 2005)	-	-	
Moira grass	-	Possible over short distances (Finlayson *et al.*, 1990)	-	-	Yes (Roberts & Martson, 2000)
ribbonweed	-	Seed pods positively buoyant (Lokker *et al.*, 1997).	Wind dispersal of seeds possible? (McFarland 2006); wind dispersal of flowers likely (Catling *et al.*, 1994)	Yes (through adhesion and ingestion by waterfowl – Catling *et al.*, 1994)	Yes (Roberts & Marston, 2000)
large fruit tassel	February in Blackwood River estuary, Western Australia (Congdon & McComb, 1979)			Ingested by waterfowl but apparently undigested (Congdon & McComb, 1980). Viability not reported.	Yes (Congdon & McComb, 1979; DOE, 2003).
tuberous tassel	Late spring-early summer (Brock, 1982b; Paton, 2005).	-	Possible	Possible (a food source for waterfowl)	Yes – turions readily detach from parent plant (Brock, 1982b)

Table 5: Propagule bank characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites

N.B. Only species for which information was identified during the current review are shown. Empty cells do not necessarily represent knowledge gaps but rather reflect a lack of information identified during the current review.

Taxa	Persistent soil seed bank?	Seed longevity	Distribution and Extent
common reed	-	3-4 years (Haslam, 1972)	-
cumbungi	Yes but small (*personal observations of authors*)	-	-
giant rush	-	-	Unlikely to survive in permanently or frequently flooded sites
lignum	No	-	-
milfoil	Yes but small (Abernethy & Wilby, 1999)	-	-
Moira grass	Yes but small (Finlayson *et al.*, 1990)	-	-
ribbonweed	Yes but small; relatively few seeds may enter seed bank (Jarvis and Moore, 2008).	Seeds may not tolerate drying (Catling *et al.*, 1994).	-
large fruit tassel	Yes? But germination from seed rare in perennial populations (Brock, 1982a). An extended "after-ripening" period may be required for germination (Brock, 1982a).	May be dormant for "long periods" (Brock, 1982b).	
tuberous tassel	Yes? But low density (Brock, 1982b; Porter *et al.*, 2007).	High (Porter, 2007).	Widespread and abundant?

4.7 Germination and seedling establishment

Germination and establishment of seedlings in riverine habitats are closely linked to hydrological conditions. Cues for germination amongst floodplain understorey and aquatic plants are frequently related to rainfall or flooding and changes in temperature, light or water availability that are associated with these (Baskin & Baskin, 1998). Typically, submerged and floating aquatic plants require submergence for germination (van der Valk & Davis, 1978; Gerritsen & Greening, 1989; Boedeltje *et al.*, 2002) while the majority of forb and monocot species favour waterlogged conditions following the recession of floodwaters for establishment and may be prevented or impeded by submergence (Capon & Brock, 2006; James *et al.*, 2007; Williams *et al.*, 2008). Germination in some species, e.g. giant rush, may be favoured by shallow flooding (Ward, 2007).

Flood timing, as well as depth, may be critical in determining germination response as some species have particular temperature requirements. Many common dryland floodplain understorey plants, however, are opportunistic and germinate in response to flooding regardless of the season (Capon & Brock, 2006). Flood duration and rates of drawdown may also influence the magnitude of germination events from floodplain soil seed banks (Capon, 2007).

The conditions which trigger germination are usually those most suitable for seedling establishment as well. Consequently, seedling establishment in most floodplain understorey plants is favoured by waterlogged or damp soil conditions while submerged and floating plants require submergence for establishment. Seedlings of some floodplain species, may be able to tolerate submergence for extended durations but exhibit very little growth under such conditions. Lignum seedlings, for example, can survive at least 6 months of flooding but demonstrate very low gains in biomass of height while submerged (Capon *et al.*, 2009). Cumbungi seedlings also grow slowly while submerged but need leaves to reach air in order to commence photosynthesis and become established (Nicol & Ganf, 2000).

Table 6 provides a summary of germination and seedling establishment characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites and the influence of flooding on these.

4.8 Plant functional groups

Aquatic and floodplain understorey plant species can be classified into broad groups, sometimes referred to as plant functional groups, based on their responses to flooding and drying. Numerous classification schemes have been developed although the most widely applied in Australia is that developed by Brock & Casanova (1997) which considers plant growth and reproduction with respect to flooding. Under this classification, submerged plants encompass species which germinate, grow and reproduce under flooded conditions while amphibious plants are those that can change their morphology depending on water presence or absence and semi-terrestrial or terrestrial species comprise those species that require periods of drying to complete their life cycles. An adaptation of this classification scheme has been developed as part of the Gunbower–Koondrook–Perricoota Forest monitoring program (Bennetts & Backstrom, 2009). In other icon sites, a range of plant classification schemes have been used that include groups such as flood intolerant, desiccation intolerant (e.g. Blanch *et al.*, 1999 in River Murray), salt tolerant and flood dependent plants (Nicol *et al.*, 2009 in Chowilla).

Table 6: Germination and seedling establishment characteristics of key floodplain understorey and aquatic plants of The Living Murray icon sites

N.B. Only species for which information was identified during the current review are shown. Empty cells do not necessarily represent knowledge gaps but rather reflect a lack of information identified during the current review.

	Germination				Establishment
Taxa	Rate	Light requirement	Temperature requirement	Water depth requirement	
common reed	Starts 10 days after submergence (Roberts & Marston, 2000)	-	Slow germination (3-4wks) in winter but rapid (6-7 days) when temp. > 25°C	Moist rather than submerged conditions (Haslam, 1972; Frankenberg, 1997)	Rare, most likely to occur following drawdown (Frankenberg, 1997)
cumbungi	Starts 4-5 days after submergence (Roberts & Marston, 2000)	Light required	>10°C but >16°C better (Roberts, 1987)	Wet mud or <5 cm depth (Froend & McComb, 1994),	Seedlings can survive submergence but require moist, warm conditions to establish (Nicol & Ganf, 2000).
giant rush	-	-	-	-	Rare, episodic recruitment (Roberts, 2006 in Abel *et al.*, 2006)
lignum	-	Need light (Chong & Walker, 2005).	Need fluctuating temperatures, 24°C /10°C optimum (Chong & Walker, 2005).	-	Rare (Chong & Walker, 2005). Favoured by damp soil (Capon *et al.*, 2009).
Moira grass	Unknown	Unknown	Unknown	Germination can occur in shallow water but 5-10 times higher in moist soil (Finlayson *et al.*, 1990).	Can establish from fragments in moist habitats (Roberts & Marston, 2000)
ribbonweed	Rapid < 7 days (Aston, 1973)	No light requirement (Aston, 1973; Jarvis & Moore, 2008); for older plants avarge irradiance > 35 µmol $m^{-2}s^{-1}$ required for shoot and leaf recruitment (Blanch *et al.*, 1998)	Germination in all seasons (Britton & Brock, 1994; Nielsen & Chick, 1997); germination rate increased over the range 13-20°C but viability was highest at 13°C (Jarvis & Moore, 2008); emergence from propagules can be predicted from degree-days (Spencer *et al.*, 2000)	-	Seedling survival increases under higher light conditions (Kimber *et al.*, 1995, in Jarvis & Moore, 2008); light important for seedling survival (Lokker *et al.* 1997).
large fruit tassel	Possible lag in response to favourable conditions (Brock, 1982b).	Seasonal change in temperature may be required (Brock, 1982b).	Seasonal change in temperature may be required (Brock, 1982b).	No specific depth but germination more likely after heavy rains that reduce salinity (Brock, 1982a).	Permanent water. Vegetative parts not tolerant of desiccation (Jacobs & Brock, 1982).
tuberous tassel	Relatively rapid, in a "pulse" (Brock, 1982b; Porter, 2007).	-	-	Shallow? Inundation in late autumn-winter (Paton, 2005). May require a wetting and drying phase to break dormancy (Brock, 1982a).	-
water primrose	Starts <1 day after flooding and completed within 5 days (Yen & Myerscough, 1989)	Need light (Yen & Myerscough, 1989)	30°C optimum (Yen & Myerscough, 1989)	Submerged and damp (Yen & Myerscough, 1989).	-

5. Effects of flooding on floodplain understorey and aquatic vegetation dynamics

5.1 Overview

Aquatic and understorey vegetation of floodplains, dryland riparian zones and other hydrologically variable wetland habitats are characterised by a high degree of temporal and spatial heterogeneity (Brock *et al.*, 2006). In such habitats, temporal shifts in vegetation composition and structure are driven primarily by flooding and complex spatial gradients of varying flood frequency, depth and duration across floodplain landscapes result in broadly predictable patterns in vegetation composition such as zonation (Capon, 2003; Brock *et al.*, 2006; Capon & Dowe, 2007).

5.2 Temporal dynamics

Flooding and drying cause significant changes in aquatic and floodplain understorey vegetation and surface water hydrology is widely recognised as the principle determinant of temporal vegetation dynamics in wetlands, riparian zones and floodplains (Capon & Dowe, 2007). Changes in vegetation composition and structure reflect varying responses to flooding and drying of different plant groups depending on their traits, age or life history stage and their interactions with flood attributes, i.e. flood timing, duration, depth etc.. Flood intolerant species, such as some *Acacia* spp. or chenopod shrubs, e.g. *Atriplex* spp. or *Sclerolaena* spp., may be killed by flooding while germination, growth and vegetative reproduction will be triggered in flood dependent species (Capon & Dowe, 2007). In other species, e.g. many annual and ephemeral forbs and monocots, germination and growth may occur primarily during the moist conditions that follow floodwater recession (Capon & Brock, 2006; Capon, 2007). In the Barmah Forest, some wetlands shift from dominance by milfoil herblands during flooding to common spike-rush sedgelands following floodwater recession (Ward, 1994). Persistence during dry periods also varies substantially between species. Extirpation of desiccation intolerant species, for example, is likely to follow exposure (Blanch *et al.*, 1999) while longer durations of drying may result in the encroachment of floodplains and wetlands by dry-adapted species (Capon, 2003).

The response of aquatic and floodplain understorey vegetation to flooding will depend on hydrological attributes including flood timing, duration, depth, rates of rise and drawdown and the time since last flood. The duration and depth of flooding, for instance, can affect the extent and likelihood of mortality in flood intolerant species. Mortality of lignum shrubs in the Cooper Creek floodplain, for example, has been observed in response to large flood events but not smaller ones (Capon, 2003). Flood duration may also influence the diversity of aquatic and understorey plant communities with longer durations likely to reduce vegetation diversity and complexity (e.g. Nielsen & Chick, 1997). The outcome of plant interactions may also be affected by flood duration. In the Barmah Forest, for example, milfoil, a competitor of Moira grass, appears to be favoured by flood durations exceeding mid-summer (Ward, 1992). The timing of flooding and drying will also be significant since many species have temperature specific germination cues or favour certain temperatures for growth (see Section 4.2). The length of time between intervening floods will determine the initial floristic composition of vegetation communities present to respond to flooding such as the presence of mature plants and the viability of propagules. Similarly, flood frequency may affect vegetation structure. In the Barmah Forest, for instance, growth of milfoil and river red gum seedlings may be promoted by permanent or very frequent inundation (Ward, 1992).

5.3 Spatial patterns

Interactions between surface water hydrology and geomorphology create complex spatial gradients of varying flood history across wetland, riparian and floodplain habitats and vegetation communities are often distributed with some degree of predictably along these (Brock *et al.*, 2006; Capon & Dowe, 2007). Lower limits of plant distribution typically reflect abiotic factors and the flood tolerance of species. In flood tolerant and dependent species, for example, lower limits are likely to depend on the ability of plants to oxygenate their rhizosphere. In contrast, a complex suite of factors will influence the upper limits of aquatic and floodplain understorey species including tolerance of exposure or drying and competition (Capon, 2003).

Patterns of species richness in floodplain and aquatic vegetation communities often reflect the Intermediate Disturbance Hypothesis with greatest diversity occurring in areas of moderate flood frequency or depth as these areas are likely to support a greater range of plant functional groups than areas at the extremes of gradients where a few flood dependent or highly competitive species persist (e.g. Capon, 2003). Some studies also suggest that vegetation diversity will be greatest along the mid-reaches of a river or along the main channel rather than tributaries (e.g. Nilsson *et al.*, 1994).

The composition and structure of soil seed banks can also vary according to flood history with greatest diversity often occurring in intermediately flooded habitats (e.g. Capon & Brock, 2006; Capon, 2007; James *et al.*, 2007). Furthermore, the abundance of propagules in soil seed banks often declines substantially in permanently, deeply or very frequently flooded habitats.

Changes to flood history resulting from river regulation or climate change can have significant effects on vegetation dynamics in aquatic, riparian and floodplain habitats and these may be evident as changes in the spatial distribution of major species and communities. Declining flood frequency, for instance, may result in the decline or local extirpation of hydrophytic species and their replacement by more mesic or xeric species causing the streamward migration of vegetation zones. Such a process may be exacerbated if the outcomes of competitive interactions between species are also influenced by changes to flood frequency. A prime example of such an occurrence can be found in the Barmah Forest, where declining flood frequency has led to the invasion of Moria grass plains by river red gum seedlings (Bren, 1992). Similarly, increased flood frequency and decreasing frequency and duration of drying may affect competitive interactions at lower elevations and the expansion of flood tolerant species higher onto the floodplain. Such a process is also occurring in Barmah Forest where increased frequency of shallow spring flooding has led to the encroachment of lower elevations of Moira grass plains by giant rush (Ward, 1992).

5.4 Vegetation responses to flow intervention

Barmah–Millewa Forest

Environmental water allocations (EWAs) were delivered to the Barmah–Millewa Forest Icon Site in both 1998 and 2000 and observations of the vegetation were made by Maunsell McIntyre (1991, 2001 in Abel *et al.*, 2006). The 1998 EWA comprised 100 GL delivered in October, increasing the duration of spring flooding and resulting in the near complete inundation of most of the giant rushlands and the grass plains (Abel *et al.*, 2006). Incidental observations suggest lush spring grass growth occurred in the red gum forest understorey following the EWA but since there was no pre-event data and neither rainfall nor grazing reductions were taken into account, this was not conclusive. Flowering of Moira grass was observed following floodwater recession from November to January but not to maximum rates with a further two months of flooding considered necessary to achieve this (Abel *et al.*, 2006). There is a suggestion by Abel *et al.* (2006) that due to the small volume involved, the 1998 EWA may have compounded problems in the Barmah–Millewa Forest Icon Site rather than contributed to ecological objectives. Reid and Quinn (2004) also monitored wetlands within the Barmah–Millewa Forest between 1998 and 2001 during which EWAs were delivered using a study design involving 'control' and 'impact' wetlands defined on the basis flood thresholds in order to detect effects of EWAs (Reid & Quinn, 2004). No detectable difference in the abundance of giant rush, Moira grass or common spike-rush was observed in sites affected by the EWA however milfoil and water primrose were significantly more abundant in 'impact' sites than in 'control' sites (Reid & Quinn, 2004). Consequently, these species have been suggested as useful indicators for future monitoring.

Gunbower–Koondrook–Perricoota Forest

EWAs comprising approximately 20,000 ML were delivered to Gunbower Forest during spring 2005 wetting between 1,000 and 2,000 ha of the forest (MDBC, 2006b). Responses to this watering were observed in numerous significant wetland species including river swamp wallaby grass, water milfoil, waxy marshwort and Moira grass (MDBC, 2006b). An EWA was also delivered in late autumn 2008 inundating twelve of the fifteen permanent and semi-permanent wetlands monitored by Ecological Associates in Gunbower Forest (Bennetts & Backstrom, 2009). This flooding resulted in the germination and establishment of a diverse range of aquatic and amphibious species although the mean cover of these was lower than that recorded previously in 2005 and 2006 (Bennetts & Backstrom, 2009).

Hattah Lakes

Environmental water was delivered to the Hattah Lakes Icon Site via a series of four pumping events between April 2005 and December 2006 resulting in the inundation of nine lakes (EPA and MDFRC, 2008). Prior to this EWA, all of the lakes were dry. Macrophyte communities developed in all of the inundated lakes though communities were distinct between lakes and changed over time, particularly in terms of increasing biomass (EPA and MDFRC, 2008). A total of 115 macrophyte species were recorded during field surveys following the EWA (EPA and MDFRC, 2008).

Chowilla Floodplain and Lindsay–Wallpolla Islands

Environmental watering occurred in the Chowilla floodplain between 2004 and 2006 and understorey vegetation response was monitored by Nicol *et al.* (2009). Significant differences were observed between pre- and post-watering surveys with a general decline in terrestrial species and an increase in flood dependent herb and grass species. Understorey response to flooding tended to be short-lived and flood dependent herb communities were observed to return to desiccation tolerant terrestrial communities in less than five months (Nicol *et al.*, 2009).

Lower Lakes, Coorong and Murray Mouth

Vegetation responses to flow interventions are complicated by the impacts of other factors on the aquatic vegetation in the LLCMM. For example, Ganf (2000) identified the following ecological needs that were required to maintain the diversity of habitat types that existed prior to flow regulation:

a. Re-establishment of the salinity gradient. This may be dependent upon operating the barrages in a manner that reflects seasonal variations in discharge. Ganf (2000) suggested that barrage removal would not guarantee the establishment of a flora resembling the pre-barrage flora.

b. Reduction of turbidity levels in the Lower Lakes. Reductions in turbidity could be achieved by flushing turbid water out to sea, re-vegetating lake shores, restricting grazing and cultivation of the riparian zone, catchment-scale vegetation to prevent wind-borne particles entering the Lower Lakes and shore line protection works.

c. Establishment of a water regime that encourages the optimal survival and growth of a diversity of flora. This includes provisions for rate of fall, duration of inundation and flooding, and maintenance of 10% of emergent leaf area at maximum operating height.

Clearly then, flow regime changes could provide several benefits to the aquatic vegetation of this Icon Site. Flow interventions may require complementary barrage operating strategies. Infrequent or occasional flow interventions may have limited benefits to aquatic vegetation. Siebentritt *et al.* (2004) investigated the effects of an enhanced Murray River flood on riparian vegetation at three sites near Renmark, South Australia (upstream of the LLCMM). Flood-tolerant and flood dependent taxa germinated but aquatic plants failed to germinate, possibly due to impoverished seed banks. The authors concluded that occasional flood interventions may have little value in restoring degraded habitats but may simply maintain existing communities.

A barrage release in 2003 (MDBC, 2005b) demonstrated problems that could be encountered in flow interventions for the LLCMM. Issues included unreliable hydrologic modelling of the mid-lower Murray, potential encroachment of saline water through the barrages when open due to "reverse head" in the Lower Lakes and Coorong, the need for real-time estimation of lake volumes and measurement of discharge through the barrages. Ecological benefits from the release were not reported.

River Murray

Siebentritt *et al.* (2004) examined riparian vegetation responses to a flow release into the River Murray in South Australia in October 2000. An increase in flow from 32,000 to 42,060 ML/day resulted from a release from an off-stream reservoir and floodplain inundation was further enhanced by the raising of a downstream weir (Siebentritt *et al.,* 2004). Germination and growth of existing flood tolerant and flood-dependent species, e.g. rat's tail couch, and senescence of flood-intolerant species, e.g. chenopod shrubs, were observed in response to this EWA but no new aquatic plant establishment was recorded (Siebentritt *et al.,* 2004).

6. Effects of flooding on floodplain understorey and aquatic weeds

6.1 Overview

Flow interventions may have undesirable consequences (e.g. Robertson & James, 2007; Howell & Benson, 2000; Souter & Walter, 2009) such as the dispersal and/or establishment and growth of weed species suited to the modified hydrological conditions. Understanding the consequences of flow interventions on weeds is critical to developing effective management of pest plant species and minimizing the risk of introduction or further spread of weed species.

Weed risk is a function of the characteristics or attributes of the weeds themselves (e.g. reproduction and dispersal characteristics and, germination, establishment and growth requirements), characteristics of the transfer or dispersal vector, the availability of suitable abiotic habitat and biological factors (such as competition, facilitation and herbivory). Weed composition and structure is likely to be influenced by the full suite of flow attributes (flood timing, depth, duration, rate of drawdown, frequency and time since last flood). Specific effects, however, will reflect varying responses to flooding and drying of different plant species depending on their attributes or characteristics and how these interact with the flooding and drying regime.

This section reviews existing information to identify the risks of weed germination, growth and dispersal with the flow characteristics identified as suitable for native understorey and aquatic vegetation. We review information on attributes of weeds with respect to hydrological parameters (flood frequency, flood timing, water depth, duration and rates of rise and fall). We use examples of weed species identified from various sources including media releases, site environmental management plans, websites (weeds of national significance) and discussion with local stakeholders as being high threats to the icon sites and focus particularly on those species considered *transformer species* (Richardson *et al.*, 2000) that have the potential to significantly impact upon the ecosystem which they are invading (Table 7). Species were selected to represent a range of plant functional groups based on their responses to flooding and drying (Casanova & Brock, 2000) and hence are likely to differ in their responses to modified hydrological regimes. We have used a simple classification (Table 7) based largely on life forms (submerged, floating, amphibious and terrestrial) as for many weed species, responses to hydrology are not well understood and hence grouping species into hydrological response categories is premature.

Table 7: Selected weed species of The Living Murray icon sites

Obligate submerged: species requiring continuous submergence unable to tolerate drying in their extant phase, Floating: species growing free floating on or near the water surface, Amphibious: species able to tolerate both exposure to air and submergence either in space (e.g. lower parts submerged and upper parts exposed) or over time (e.g. able to grow submerged and on damp or water logged ground), Terrestrial: species that are intolerant of prolonged submergence although may germinate on damp or water logged ground.

Family	Species	Common name	Functional group
Alismataceae	*Alisma lanceolatum* *Sagittaria platyphylla*	water plantain arrow head	Amphibious
Asteraceae	*Xanthium occidentale,* *Xanthium orientale,* *Xanthium spinosum*	Noogoora burr Californiana burr Bathurst burr	Terrestrial/ amphibious
Boraginaceae	*Echium plantagineum*	patersons curse	Terrestrial
Convolvulaceae	*Cuscuta campestris*	golden dodder	Terrestrial
Haloragaceae	*Myriophyllum aquaticum*	parrot's feather	Amphibious
Hydrocharitaceae	*Egeria densa* *Elodea canadensis*	dense waterweed Canadian pondweed	Obligate submerged
Pontederiaceae	*Eichhornia crassipes*	water hyacinth	Floating
Salviniaceae	*Salvinia molesta*	salvinia	Floating
Verbenaceae	*Phyla canescens*	lippia	Amphibious

6.2 Growth

Growth of the extant weed community is likely to be influenced by the full suite of flow attributes considered here (flood timing, depth, duration, rate of drawdown, frequency and time since last flood). Specific responses to hydrology, however, are likely to depend upon interactions between hydrology and, the morphological, physiological and life history characteristics of the plants. Plants in the terrestrial group are unlikely to survive flooding. A recent study (Stokes & Colloff, 2009) suggests that reduced flood frequency has increased the abundance of exotic annual weed species in the River Murray system. The majority of the exotic species identified in the study of Stokes and Colloff (2009) were described as terrestrial species preferring drier conditions. Whilst flooding is unlikely to advantage terrestrial species directly seedling establishment may benefit from disturbances and may be able to take advantage of dry conditions post-flooding when competing vegetation or litter have been removed.

For species in the submerged, floating and amphibious groups, the effects of flood timing depend upon species' seasonal growth patterns and are largely a function of temperature and day length preferences. The growth of aquatic weed species (submerged, floating and amphibious) reviewed here is likely to be promoted by flooding during warmer months of the year but specific effects depend upon species seasonal growth patterns.

Water depth is likely to be relevant for amphibious weeds with specific water depth ranges. For example, *Sagittaria platyphylla* (arrow head) established in the Barmah Forest wetlands appears to prefer relatively constant water levels in slow flowing areas within the water depth range 0–30 cm and is intolerant of deep waters (Maxwell, 2008). *Xanthium occidentale* (Noogoora burr) is reported to be relatively flood tolerant at all growth stages (Parsons & Cuthbertson, 2001) but will not tolerate prolonged (>4 weeks) total submergence (Nicol, 2004). Water depth may also be important for submerged aquatic species. Submerged species vary in their light compensation points (the level of illumination at which photosynthetic fixation of carbon dioxide equals respiratory loss) and species with low light compensation points are likely to be able to establish in deep and/or turbid floodplain waters whilst those with higher compensation points may be restricted to shallower waters. *Elodea canadensis* (Canadian pondweed), for example, is considered to be relatively light demanding (Bowmer *et al.*, 1984) and hence is likely to be limited to relatively shallow waters particularly if water transparency is low.

A longer duration of flooding is likely to promote growth of submerged, floating and some amphibious weed species. Impact of duration, however, is dependent upon flood timing. Floods during warmer periods are likely to promote growth to a greater degree than increased duration over winter. For some amphibious weeds, increases in duration of flooding may cause mortality of extant vegetation. Again, effects vary depending upon specific flood tolerances of species. For example, the work of Blanch *et al.* (1999) suggests that *Phyla canescens* (lippia) is unlikely to survive flooding of more than 164 days in a two year period (or between 20–25% of the time) which corresponds with the observations of Earl (2003). Other species such as *X. occidentale* described as tolerating shallow flooding (Cunningham *et al.*, 1981) may suffer mortality if submerged for extended periods (Nicol, 2004).

6.3 Vegetative reproduction

Vegetative reproduction is extremely common in wetlands (Cronk & Fennessy, 2001). As described in section 4 of this report, species may spread vegetatively via a number of different mechanisms (for example stem fragments, stolons, rhizomes, tubers, turions etc.). For some weed species this is the only (*Egeria densa, Elodea canadensis* and *Salvinia molesta*) or dominant (*Eichhornia crassipes*) mechanisms of spread in Australia whilst for other species reproductive strategy (sexual or asexual) may depend upon environmental conditions. In *P. canescens*, for example, asexual reproduction is promoted during top flooding (Taylor & Ganf, 2005) but this species also spreads by seed.

Hydrological factors that influence plant growth (reviewed in section 6.2) are likely to influence their vegetative reproduction impacting upon both the abundance and quality or viability of vegetative propagules. For example, morphological changes in *P. canescens* as a result of submergence result in fragile stems which fragment easily (Earl, 2003). The detached stems can then disperse and establish at new locations. Timing of flood may also be important for the colonisation ability of vegetative propagules. Stem fragments of *E. canadensis* were found to have significantly better survival rates in temperate climates in spring (May) compared with autumn but fragments have very high regeneration ability irrespective of season (Barrat-Segretain & Bornette, 2000).

6.4 Sexual reproduction

Sexual reproduction, whilst less common in wetlands, may be important for particular habitats or groups of species. Annual terrestrial weeds such as *Echium plantagineum* (patersons curse) typically reproduce only by seed. Water depth and rate of drawdown may be important triggers for seed production in some amphibious species. Deep water may inhibit seed production in some weeds. For example, seeding in *Alisma lanceolatum* was found to be prohibited at water depths of 80 cm (Moravcova *et al.*, 2001). Quantity of seed may also be affected by moisture availability. For example, low water availability was found to reduce burr production of *X. occidentale* (Martin & Carnahan, 1984). Seed production can also be influenced by plant sex, age and size, the latter reflecting the various influences of hydrology on growth (section 6.2).

6.5 Propagule dispersal

Dispersal by water is important to wetland ecosystems as many propagules are dispersed by water even those without any specialized buoyancy devices (Markwith & Leigh, 2008). Seeds may be dispersed many kilometres in water and seed buoyancy influences the distribution of seeds within and between wetlands. Unless extant plants persist over time, species without an *in situ* persistent propagule bank require re-inoculation of sites with propagules from outside each time conditions become suitable for growth. For example, submerged macrophytes such as *Elodea canadensis* and *Egeria densa* require permanent surface waters and have no desiccation tolerant propagule bank hence even when hydrological conditions are suitable (i.e. the presence of surface waters), invasion is dependent upon re-inoculation with viable propagules. Propagule availability is likely to strongly limit the ability of weeds to invade a particular site and, in particular, will influence those species that require re-inoculation each time hydrological conditions become suitable.

Specific aspects of the flow regime that may influence propagule dispersal in water include flood timing, magnitude, duration and frequency. Timing of floods may be important with respect to species dispersal seasons. Effective dispersal by water is likely to be greater if floods are synchronised with timing of seed availability. As species differ in both timing and duration of propagule production the effects of flood timing are likely to be species specific. The importance of flood timing with respect to dispersal is likely to be greatest for species with short-term seed viability and short dispersal seasons as the chances of a flood being out of synchrony when viable seed are available are high. Flood magnitude influences the ability of a dispersed propagule to reach a specific location thereby determining the extent of propagule dispersal whilst flood duration will influence the abundance of propagules reaching a specific site. Flood frequency will influence the number of introductory events which is relevant to invasion success because multiple introductions increase the chances of a successful establishment (Lockwood *et al.*, 2005).

Information on hydrochory in general and, in particular, on the dispersal of weed propagules by water is poor for Australian systems (Groves *et al.*, 2009). Information on nearly all the species reviewed here suggests that hydrochory is an important mechanism for dispersal. For example, Roberts *et al.* (1999) believed flooding facilitated the downstream dispersal of egeria in the Hawkesbury–Nepean River. Likewise, dispersal of *P. canescens* is thought to be related to flooding (Earl, 2003) whilst dispersal of *Sagittaria platyphylla* seeds through waterways has probably facilitated this species spread (Maxwell, 2008). Terrestrial species are likely to be less reliant on water for seed dispersal but seeds may nevertheless be transported in floodwaters (for example the burrs of *Xanthium* spp.; Cunningham *et al.*, 1981). It is important to note, however, that even for seeds that are not dispersed primarily by water, hydrology may still influence the activities or movements of other dispersal vectors such as animals or birds.

6.6 Propagule banks

Propagule banks reflect processes that replenish the propagule bank (e.g. dispersal and seed production) and deplete the propagule bank (secondary dispersal, germination or growth and, propagule mortality due to predation, age, bacterial or fungal attack, rotting etc.). Seeds of some species may persist for many years. Seeds of *Eichhornia crassipes*, for example, may remain viable for up to twenty years (Burton, 2005) whilst unpublished research suggests that *P. canescens* has seed longevity possibly in excess of 10 years (NLWG, 2009). Vegetative propagules, on the other hand, are generally short-lived and desiccate rapidly on exposure to air. Propagule longevity for most weed species is unknown as is knowledge of environmental factors likely to affect seed longevity and viability such as storage conditions (propagule tolerance to flooding or drying for example) although the seeds of many aquatic species appear to tolerate flooding (Baskin & Baskin, 2001).

6.7 Germination and seedling establishment

Germination requirements such as specific temperature, light, oxygen and/or pH conditions are influenced by flooding and drying regimes. Flow attributes likely to be important in determining germination responses include flood timing, depth, duration and rate of drawdown. The seeds of many aquatic species do not germinate at temperatures below 15°C and require light for germination (Baskin & Baskin, 2001) hence flood timing and water depth are likely to be important, the latter particularly where floodwaters are turbid. Seeds of many aquatic species can also tolerate prolonged flooding but most do not germinate until waters recede (Baskin & Baskin, 2001). Drawdown appears to trigger germination of *Xanthium occidentale* (Nicol, 2004) and hence longer periods of drawdown are likely to provide greater opportunities for the germination of weed species such as *X. occidentale* that prefer damp or waterlogged soils for germination. Unpublished research conducted at the University of New England suggests flooding is required for the germination of *P. canescens* seeds (NLWG, 2009). On the other hand, seeds of *Alisma lanceolatum* appear to germinate under a wide variety of moisture conditions including drying and flooding (Preston & Croft, 1997; Moravcova *et al.*, 2001). Information on weed germination responses particularly in relation to moisture availability is sporadic as is information on seedling tolerances to flooding and drying.

6.8 Brief species biographies

Obligate submerged species

Egeria densa (dense waterweed) and *Elodea canadensis* (Canadian pondweed) are obligate submerged perennial herbs. Both species are listed as aquatic weeds for the Interim Biogeographic Regionalisation of Australia Riverina region (Thorp & Wilson, 1998). *E. densa* is currently the subject of a controlled drawdown of Yarrawonga weir at Lake Mulwala in an attempt to control its spread (MDBA, 2009). *E. canadensis* has been a major pest of waterways in NSW and Victoria where it constricts flow (Bowmer *et al.*, 1984).

Both *E. densa* and *E. canadensis* spread primarily through vegetative means (Sainty & Jacobs, 2003; Bini & Thomaz, 2005) and are not known to set seed in Australia (Parsons & Cuthbertson, 2001). Vegetative fragments generally have little or no drought tolerance although vegetative propagules such as turions (specialised overwintering vegetation fragments) may survive short periods if the substrate remains damp. For example, an experimental drawdown conducted in Europe suggested vegetative fragments of *E. canadensis* can survive for up to 8 days in damp mud (Barrat-Segretain & Cellot, 2007). Stem fragments of *E. densa* and *E. canadensis* that include a couple of leaf nodes are capable of regenerating (James, 1999; Parson & Cuthbertson, 2001; Riis *et al.*, 2009) and timing of flood disturbances may be important for the colonisation ability of vegetative propagules. Sainty & Jacobs (2003) state that the main period for vegetative dispersal is autumn. Stem fragments of *E. canadensis*, however, were found to have significantly better survival rates in temperate climates in spring (May) compared with autumn but fragments have very high regeneration ability irrespective of season (Barrat-Segretain & Bornette, 2000).

Both *E. densa* and *E. canadensis* are reported to favour still or slowly flowing waters (Sainty & Jacobs, 2003). *E. densa* can tolerate flooding (Feijoo *et al.*, 1996) and Roberts *et al.*, (1999) believed flooding facilitated the downstream dispersal of the species in the Hawkesbury–Nepean River.

Increased duration of water retention during summer may favour the growth of these species, depending upon turbidity and light availability. Growth of submerged species is usually arrested or reduced at water temperatures below approximately 10–15° C and species often show highest growth rates between temperatures of 20–35° C (Parsons & Cuthbertson, 2001). The growth of both species is dependent upon light availability (Bowmer *et al.*, 1984; Tanner *et al.*, 1993; Sainty & Jacobs, 2003; Bini *et al.*, 2005) and therefore retention of turbid water on floodplains may inhibit growth.

Floating species

Salvinia molesta (salvinia) and *Eichhornia crassipes* (water hyacinth) are both free floating aquatic plants. Both species are considered important aquatic weeds with the former named a weed of national significance (Agriculture & Resource Management Council of Australia & New Zealand, Australian & New Zealand Environment & Conservation Council and Forestry Ministers, 2000).

Salvinia molesta and *E. crassipes* are reliant on permanent water although, like obligate submerged species, may survive for short periods on damp ground (e.g. Thorp & Wilson, 1998). *S. molesta*, a floating fern, does not produce viable spores in Australia (van Oosterhout, 2006) and survival of drought periods will generally be relatively short-lived unless moisture is retained, for example, beneath thickly layered vegetation. *E. crassipes* requires permanent surface waters for extant vegetative growth. However this species also has longed-lived persistent seed bank (up to twenty years; Burton, 2005) which may enable this species to re-establish after many years of drought. Both species can spread extremely rapidly via vegetative growth with the development of daughter plants on stolons or stems. These 'daughter plants' may become detached from the mother plant and form new independent colonies.

The growth of both *S. molesta* and *E. crassipes* is favoured by nutrient rich still or slow moving waters (Parson & Cuthbertson, 2001). Establishment of *E. crassipes* is advantaged by reasonably stable water levels (Pressey & Middleton, 1982). Temperature is also an important factor governing the growth rate of floating plants. The growth of floating species like that of submerged species is probably promoted by flooding during warmer months of the year. *E. crassipe* has an optimum temperature range of 25–30° C with maximum growth temperatures between 33 and 35° C (Kasselmann, 1995). It is able to survive short term exposure to near-freezing temperatures (<5° C) but winter draw-downs that expose plant parts to prolonged low air temperatures has been suggested as a potential management strategy (Owens & Madsen, 1995). The optimum growth temperature for *S. molesta* is reported to be approximately 28–30° C with long term exposure to temperatures above 39–40° C probably lethal (van der Heide *et al.*, 2006). These temperature ranges suggest that spring/summer flooding will promote the growth of both *S. molesta* and *E. crassipes*.

Amphibious species

Sagittaria platyphylla (synonym *Sagittaria graminea ssp. platyphylla*) (arrow head) is a perennial emergent herb although it may also behave as an annual, germinating in spring and flowering in summer (Sainty & Jacobs, 2003). This species has become established in the northern Victoria river network and can be found at a number of sites along the River Murray (Maxwell, 2008).

Sagittaria platyphylla may be spread by seed, rhizomes and tubers (Parsons & Cuthbertson, 2001). Disturbance by livestock and European carp and herbivory by a variety of fauna are thought to aid the spread of both seed and vegetative propagules (Maxwell, 2008). *S. platyphylla* is reported to prefer relatively constant water levels in slow flowing areas within the water depth range 0–30 cm and is intolerant of deep waters (Maxwell, 2008). This depth range concurs with that of 30 cm reported by Martin and Shaffer (2005). According to Martin and Shaffer (2005), however, *Sagittaria* spp. species are often able to survive dramatic fluctuations in water level. This species appears to be relatively drought intolerant with a substantial reduction in infestations following drought in the Barmah and Millewa Forests wetlands (Maxwell, 2008). Summer flooding appears to be advantageous to this species (Maxwell 2008).

Alisma lanceolatum (water plantain) is a perennial emergent herb dispersed by seeds and tubers (Preston & Croft, 1997; Sainty & Jacobs, 2003). This species is a serious weed of rice in NSW and is distributed in shallow still waterbodies of New South Wales, Victoria and South Australia (Sainty & Jacobs, 2003).

Alisma lanceolatum has a relatively broad germination temperature range although is found predominantly in warm temperate climates of Europe (Moravcova *et al.*, 2001). Seeds of *A. lanceolatum* appear to germinate very easily and are able to germinate on dry ground (Preston & Croft, 1997) or under shallow flooding (4 cm water depth) and waterlogged conditions (Moravcova *et al.*, 2001). Seeds may float for long periods with the aid of a buoyant pericarp or fruit wall (Kaul, 1978), can be dispersed on the feet of waterfowl and may remain viable after passing through the digestive tract of birds (Preston & Croft, 1997). Seeds may also remain dormant for long periods (Preston & Croft, 1997). Seedlings at least one year old can survive submergence to depths of 40–80 cm but flowering is suppressed at 80 cm water depths (Moravcova *et al.*, 2001).

Phyla canescens (lippia) is a prostrate perennial herb that spreads by both seed and vegetative propagules (Leigh & Walton, 2004). This species is a major weed of the Murray–Darling Basin (Leigh and Walton, 2004) and is present within the lower River Murray system (Souter & Walter, 2009; Henderson *et al.*, 2008). In his recent risk assessment, Nicol (2007) categorised this species as of extreme invasion/expansion risk in the Chowilla system.

Phyla canescens flowers in spring, summer or autumn in response to flooding or local rainfall (Lucy *et al.*, 1995 cited in Leigh & Walton, 2004). Unpublished research conducted at the University of New England and reported in the Lippia Management Manual (NLWG, 2009) suggests seed densities may be high (1,000–10,000 per m² in dense lippia beds) with a germination rate of approximately 50% and seed longevity possibly in excess of 10 years. Other studies, however, suggest a relative small soil seed bank (McCosker, 1994). When inundated morphological changes occur with internode thickening and stems become fragile and easily fragmented. These stem fragments may lay dormant for up to three months (Dellows, 2001).

Unpublished research on *P. canescens* (NLWG, 2009) suggests this species has a wide temperature range for germination. Germination is significantly reduced below 15° C and above 45° C and when temperatures fluctuate by less than 10° C. Lippia seeds are reported to require flooding for germination (NLWG, 2009) and germination temperature preferences would suggest this species' establishment is promoted by flooding during warmer months when temperatures exceed 15° C.

Phyla canescens has a deep tap root and is relatively drought tolerant (Lucy *et al.*, 2005 cited in Taylor & Ganf, 2005). It is also reported to survive inundation for 2–3 months each year in water depths in excess of one metre (Earl, 2003). The work of Blanch *et al.* (1999) suggests that *P. canescens* is unlikely to survive flooding of more than 164 days in a two year period (or between 20–25% of the time) which corresponds with the observations of Earl (2003) and seems to require continuous exposure of at least 283 days in a two year period. Modelling suggests that flood duration of 13 weeks would maximise the spread of *P. canescens* (Barry *et al.*, 2007).

Myriophyllum aquaticum (parrot's feather) is a submerged/emergent perennial herb capable of persisting as an emergent form on damp ground. It is commonly found in still or slowly flowing waters (Preston & Croft 1997; S. Mackay personal observation). *M. aquaticum* spreads only by vegetative fragments in Australia (Orchard 1985). The stems are brittle and small stem fragments can establish new plants (Preston & Croft, 1997). It may have a low tolerance to flood disturbances – in southeast Queensland this species occurs in high abundances downstream of dams (e.g. Hinze Dam on the Nerang River and Wappa Dam on the South Maroochy River) but is rarely seen in unregulated waterways (S. Mackay personal observation).

Terrestrial/amphibious

Xanthium occidentale (Noogoora burr), *Xanthium orientale* (Californian burr) and *Xanthium spinosum* (Bathurst burr) are annual herbs. *Xanthium* spp. are named as significant weeds of the Chowilla floodplain (MDBC, 2006d; Nicol 2007).

Dispersal of *Xanthium* spp. is by seed (Parsons & Cuthbertson, 2001). The hooked spines of the burrs facilitate their dispersal by animals and, air cavities inside the burrs also provide buoyancy assisting their dispersal in water (Parsons & Cuthbertson, 2001). All three species grow predominantly during summer but seedlings of *X. spinosum* emerge from spring to autumn in response to rainfall (Auld, 1993). Nicol (2004) described *Xanthium occidentale* as having a transient seed bank.

Xanthium occidentale and *X. orientale* both tolerate flooding at all growth stages and are often found growing in floodplain areas after floodwaters have receded (Parsons & Cuthbertson, 2001; C. James *personal observation*). *X. occidentale* will not tolerate top flooding for more than four weeks but is able to survive partial flooding producing adventitious roots (Nicol, 2004). Partial submergence caused submerged parts of the stem of *X. occidentale* to loose rigidity and collapse when support provided by water was removed, despite this the plants were still able to grow as the adventitious roots took root in the soil (Nicol, 2004). This species appears to prefer non-flooding conditions and does not appear to be able to survive water depths of 70 cm (Nicol, 2004).

Terrestrial

Echium plantagineum (patersons curse) is a winter annual or short lived perennial herb. It is a common exotic species of the River Murray (Stokes & Colloff, 2009). Spread of *E. plantagineum* is by seed with large numbers of seeds produced per plant. Seed dispersal occurs during December and January. Seeds may persist in the soil seed bank for up to six years (Groves *et al.*, 1995). Most seeds germinate in autumn in response to rainfall. This species is described as a terrestrial species preferring drier conditions and germinating, growing and reproducing in the absence of surface waters (Stokes & Colloff, 2009). Flooding is unlikely to advantage this species directly although seedling establishment of this species does appear to benefit from disturbances and may be able to take advantage of dry conditions post-flooding when competing vegetation or litter have been removed (Grigulis *et al.*, 2001).

Cuscuta campestris (golden dodder) is a terrestrial parasitic annual herb. *C. campestris* is identified as significant weeds of the Chowilla floodplain (MDBC, 2006d; Nicol, 2007). Germination of this species is optimal at 30°C and negligible below 15°C (Benvenuti *et al.*, 2005). Seedlings are without roots and need to make contact with a host plant within a few weeks of germination in order to survive (Benvenuti *et al.*, 2005). Seeds do not appear to germinate under flooded conditions hence flooding during warmer months may prohibit the germination and establishment of this species.

7. Conceptual models

7.1 Overview

In this section, we present a series of conceptual models intended to depict the principle effects of flooding on floodplain understorey and aquatic plants. The purpose of these models is primarily to:

i. synthesise the information presented in preceding sections and include other pertinent information specific to particular taxa or communities not included in the text but identified during this review process;
ii. identify major knowledge gaps in order to prioritise future research; and
iii. provide a base from which future conceptual model development can occur.

7.2 Approach

In order to address the objectives of this project, we developed three sets of conceptual models. The first of these describe relationships between key flow attributes and major life history stages of selected floodplain understorey and aquatic taxa of The Living Murray icon sites. The second set depicts relationships between these same key flow attributes and major elements and processes shaping vegetation dynamics in selected floodplain understorey and aquatic plant communities of The Living Murray icon sites. The third set concerns weeds.

The key flood pulse attributes considered in these models are:

- flooding timing: i.e. season
- flood duration
- flood depth: refers to damp vs. waterlogged vs. submerged state as well as depth of submergence
- rate of drawdown: refers to rates of floodwater recession and subsequent duration of waterlogged and damp conditions
- time since last flood
- flood frequency.

It should be noted that these conceptual models reflect the information reviewed in this report. Consequently, absence of a flood attribute from a life history process does not necessarily mean this attribute is not influential but rather that information regarding its role has not been identified during the current project. Furthermore, there are many non-hydrological factors, e.g. grazing, salinity, that are likely to play a significant role in the life histories and vegetation dynamics of floodplain and aquatic vegetation of The Living Murray icon sites and many of these are likely to be influenced by hydrology. Given the objectives and limited timeframe of the current project however we have not considered these in the development of these conceptual models.

Major knowledge gaps are highlighted.

7.3 Conceptual models for selected taxa

Floodplain understorey and aquatic taxa were selected on the basis of their significance, dominance and prevalence across The Living Murray icon sites as well as the availability of relevant information. The taxa selected were:

- common reed
- cumbungi
- giant rush
- lignum
- milfoil
- Moira grass
- rat's tail couch
- ribbonweed
- tuberous tassel
- large-fruit tassel.

A generic model outlining the main effects of flood attributes on floodplain understorey and aquatic plants is presented initially (Fig. 1) following specific models for the selected taxa (Figures 2–11). The prevalent reproductive pathway, i.e. asexual vs. sexual, of taxa is also indicated in models by thicker lines connecting stages of regeneration.

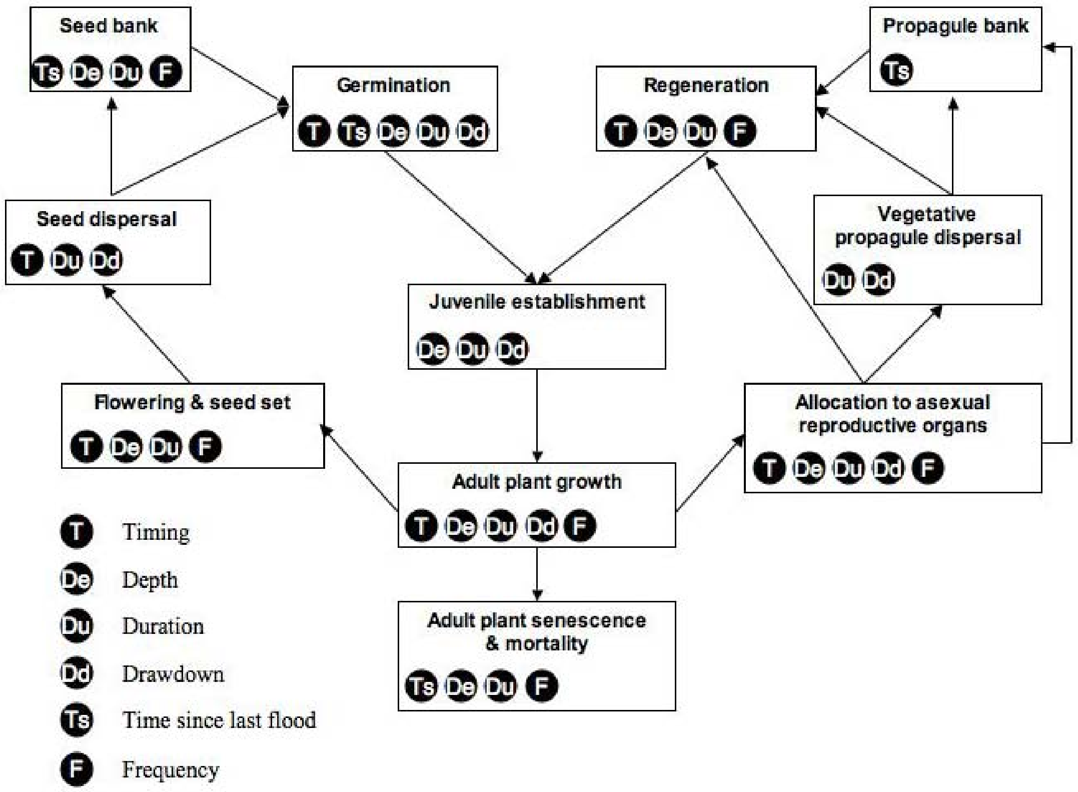

Figure 1: Conceptual model of effects of key flood attributes on major life history processes of a generic floodplain understorey or aquatic plant

Explanatory notes—generic floodplain understorey or aquatic plant conceptual model (Figure 1)

Plant growth, senescence & mortality

Growth of adult floodplain understorey and aquatic plants has the potential to be influenced by the range of flood attributes discussed here. Flood timing can affect rates of growth as these may differ between seasons. Depth of submergence will influence the availability of resources, e.g. light and soil oxygen, and duration will determine the length of time habitat changes persist. Frequency of flooding may also affect the amount of growth that occurs in adult plants. Where hydrological thresholds for plant growth are exceeded, e.g. exposure or extended durations of drying, deep or permanent flooding, plants are likely to senesce and die.

Flood depth and duration are likely to be critical in determining the successful establishment of juvenile plants since these will have different tolerances than adult plants to habitat changes wrought by flooding or drought. Rates of drawdown may also be influential as these will affect the duration of soil moisture availability into periods of drying and therefore the ability of seedlings to grow to a size which is capable of tolerating drying or further flooding.

Vegetative reproduction

Flooding will probably interact with a plant's allocation of biomass to asexual reproduction in a similar manner to its influence on plant growth as production of rhizomes, stolons, turions etc., is likely to be governed by overall rates of biomass accumulation. In some species, e.g. Moira grass, changes in water depth or rates of drawdown may also trigger a shift from sexual to vegetative reproductive strategies. If dispersal of vegetative propagules e.g. fragments, occurs, the amount and type of propagules dispersed are likely to be influenced by flood depth and duration as is the distance dispersed. The viability of any vegetative propagule banks, e.g. buried rhizomes, will be closely related to the time since last flood event since vegetative propagules will have limited life spans.

Regeneration from vegetative propagules may be influenced by flood timing, since certain temperatures may be favourable for initiating growth in some species, and flood depth and duration, since these may affect triggers for growth, e.g. light, and possibly the viability of propagules.

Sexual reproduction

Flowering and seed production may be influenced by flood timing as some species may only initiate sexual reproduction in particular seasons. Flood depth and duration may also be important as these will determine if suitable conditions are available for pollination and fertilisation, e.g. contact with air. Drawdown of floodwaters can trigger a switch from asexual to sexual reproduction or vice versa in some species, e.g. Moira grass. If a plant maintains a persistent soil seed bank, the abundance of viable and germinable seeds will be influenced by the time since last flood event, since seeds will have a limited life span, flood depth and duration, since many seeds rot in deeply or permanently flooded habitats and flood frequency, since hydrochory may deliver greater numbers of seeds to moderately flooded areas and scour seeds from very frequently flooded habitats.

Seed germination may be affected by flood timing, since many species have cues related to temperature, the time since last flood event, as this may affect dormancy-breaking, and flood depth, since this will influence light availability. Flood duration can also be important since some species do not initiate germination unless moisture levels persist for a certain period of time. Rates of drawdown may similarly influence the duration of soil moisture availability for germination.

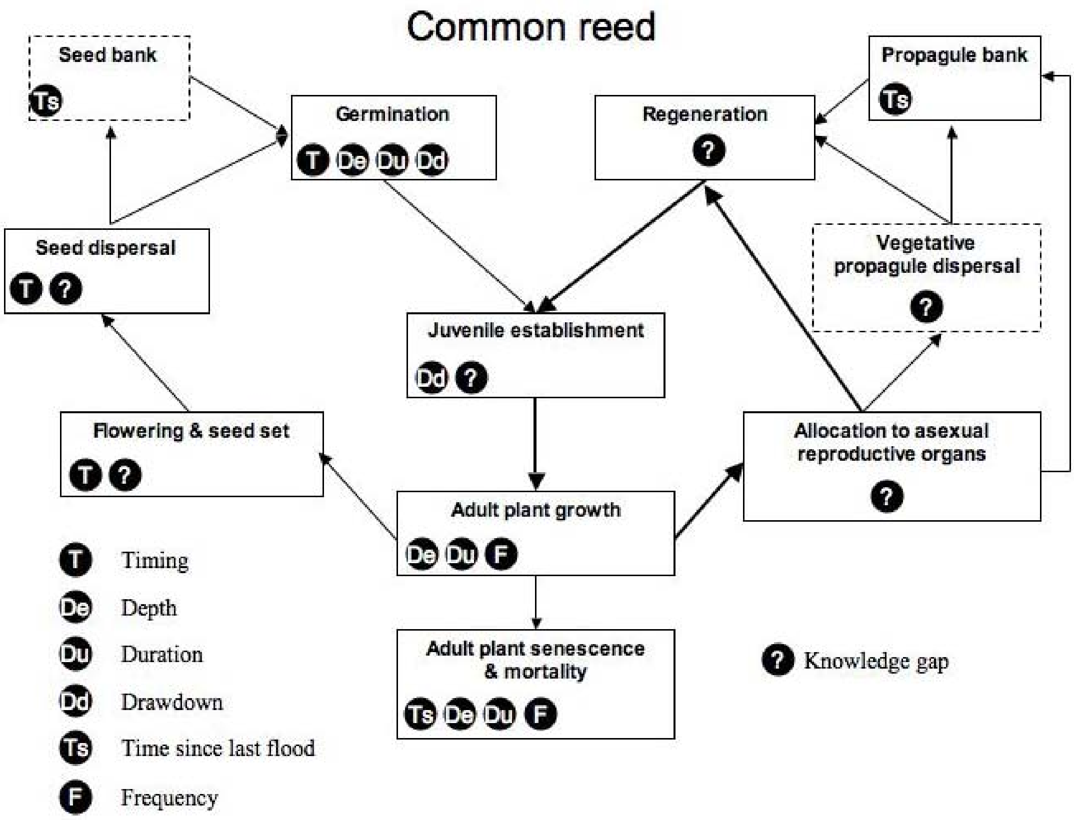

Figure 2: Conceptual model of effects of key flood attributes on major life history processes of common reed (*Phragmites australis*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—common reed conceptual model (Figure 2)

Plant growth, senescence & mortality

Whilst common reed can tolerate fluctuating water levels (Roberts & Marston, 2000), growth is favoured by shallow flooding (Ostendorp, 1991). Plants can however tolerate depths of up to 1.5 to 2 m. On the lower Murray, common reed occurs in places that flood between 80 and 225 days a year (Blanch *et al.*, 1999). Extended durations of flooding will result in senescence and mortality (Roberts & Marston, 2000).

Vegetative reproduction

Common reed is known to spread via rhizomes (Roberts & Marston, 2000) and stolons (Cronk & Fennessy, 2001) and vegetative reproduction appears to be the primary means of regeneration in this species. Rhizomes can survive drying for a few years when buried in clays to at least 0.5m depth (Roberts & Marston, 2000).

Sexual reproduction

Common reed flowers from autumn to late summer in south-eastern Australia (Frankenberg, 1997; Roberts & Marston, 2000). Levels of flower sterility and seed production are known to vary spatially and temporally according to the degree of stress experienced by plants (Frankenberg, 1997). Seeds that are dispersed in autumn (Roberts & Marston, 2000) may float for up to 3 days (Coops & van der Velde, 1995) and retain viability for up to 3 to 4 years (Haslam, 1972). Germination commences ten days following submergence (Roberts & Martson, 2000) and is slow (3–4 weeks) in winter and rapid (6–7 days) when temperatures are over 25°C. Germination is favoured by moist rather than submerged conditions (Haslam, 1972; Frankenberg, 1997). Overall, however, recruitment of common reed via sexual reproduction is rare and most likely to occur following drawdown of floodwaters (Frankenberg, 1997).

Knowledge gaps

- flow requirements for seedling establishment
- effects of flow on allocation to asexual or sexual reproduction
- occurrence of vegetative propagule dispersal and regeneration and relationships to flow
- factors influencing the distribution, abundance and viability of vegetative propagule banks, e.g. buried rhizomes, regeneration from these
- occurrence of soil seed banks and factors influencing their distribution, abundance and viability and seed dispersal.

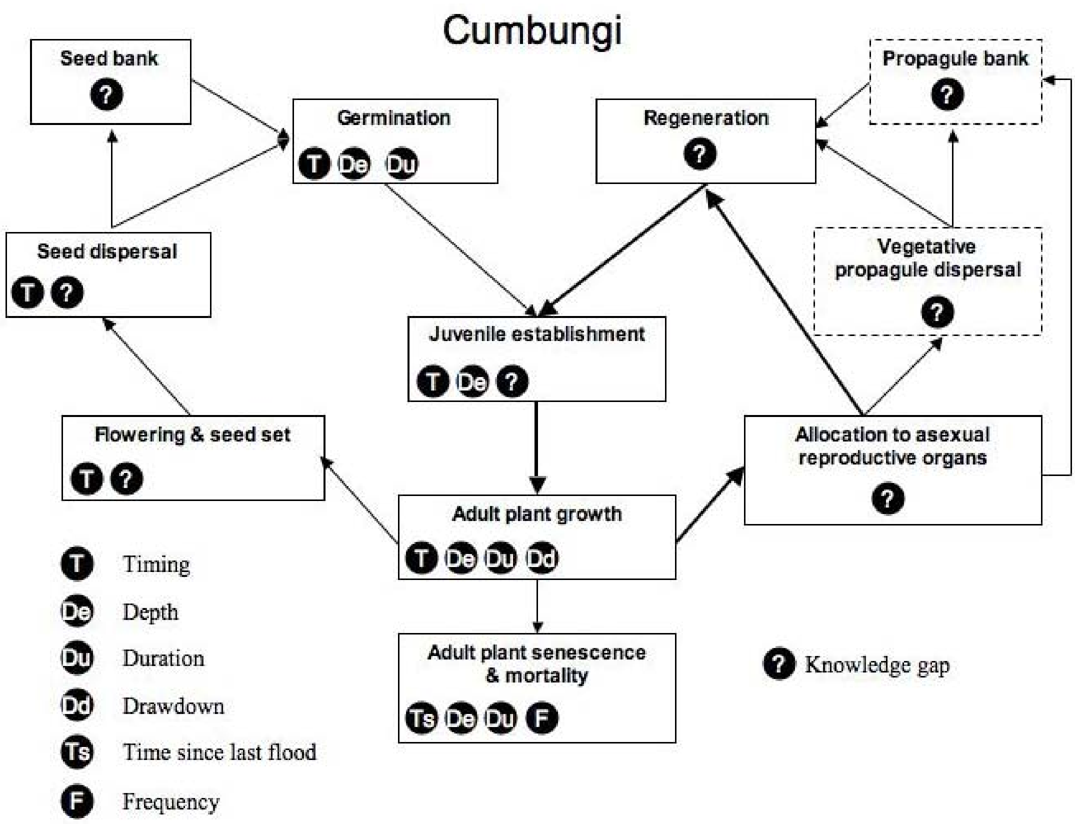

Figure 3: Conceptual model of effects of key flood attributes on major life history processes of cumbungi (*Typha* spp.)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—cumbungi conceptual model (Figure 3)

Plant growth, senescence & mortality

Cumbungi can grow rapidly under favourable conditions, reaching 1 m with a rhizome within a few months (Nicol & Ganf, 2000). This taxa is favoured by a stable water regime, particularly early in the growing season, and usually grows in areas that are permanently wet or moist with water depths of less than 2 m (Ward, 1996; Roberts & Marston, 2000; Blanch *et al.*, 1999). Growth is favoured by a wet spring and summer (Roberts & Marston, 2000) with leaf growth slowing in winter. After mid-summer, shoots senesce and growth is mainly below ground with allocation to carbohydrate storage and rhizomes (Roberts & Marston, 2000). Cumbungi can tolerate 9 to 12 months of flooding but 9 months is considered optimum in northern Victoria (Ward, 1996). Plants can also tolerate up to 3 to 4 months of drying in summer to autumn following the growing season (Roberts & Marston, 2000).

Vegetative reproduction

Cumbungi can spread via rhizomes (Cronk & Fennessy, 2001).

Sexual reproduction

Cumbungi flowers in spring to summer and produces large numbers of seed, i.e. >1000 per inflorescence (Roberts & Marston, 2000). Seeds are dispersed by wind in late summer to early autumn (Roberts & Marston, 2000). Small but persistent soil seed banks may be maintained by cumbungi (*personal observation of authors*). Germination of seeds commences 4 to 5 days following submerged under light conditions (Roberts & Marston, 2000). Germination occurs when temperatures are greater than 10°C but is favoured by temperatures over 16°C (Roberts, 1987) and occurs in wet mud or when floodwaters are less than 5 cm deep (Froend & McComb, 1994).

Cumbungi seedlings are able to survive submergence but will only establish under moist, warm conditions (Nicol & Ganf, 2000).

Knowledge gaps

- effects of flow on allocation to asexual or sexual reproduction
- occurrence of vegetative propagule dispersal and regeneration and relationships to flow
- factors influencing the distribution, abundance and viability of vegetative propagule banks, e.g. buried rhizomes, regeneration from these
- occurrence of soil seed banks and factors influencing their distribution, abundance and viability and seed dispersal.

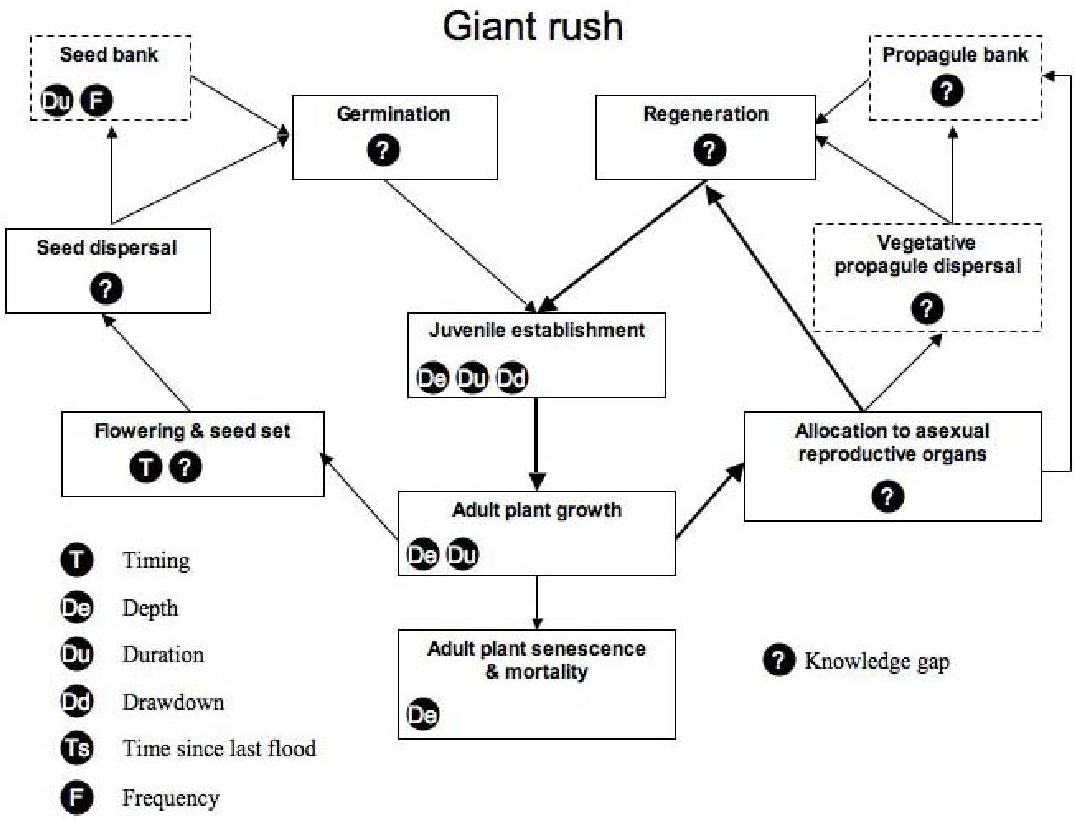

Figure 4: Conceptual model of effects of key flood attributes on major life history processes of giant rush (*Juncus ingens*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—giant rush conceptual model (Figure 4)

Plant growth, senescence & mortality

Giant rush grows in up to 1.5 m of water in northern Victoria (Ward, 1996) but cannot tolerate deep flooding (Brix *et al.*, 1992). The optimum flood duration for giant rush growth is 9 months but the plant occurs in northern Victoria where winter to spring flooding lasts from 6 to 11 months (Ward, 1996).

Sexual reproduction

Giant rush flowers during flooding in spring (Ward, 1992) and has the capacity for high levels of seed production under favourable conditions (Roberts, 2006 in Abel *et al.*, 2006). Seeds are unlikely to survive in permanently or frequently flooded sites (MDBC, 2005a).

Knowledge gaps

- effects of flow on allocation to asexual or sexual reproduction
- occurrence of vegetative propagule dispersal and relationships to flow
- occurrence of vegetative propagule banks and factors influencing their distribution, abundance, viability and regeneration from these
- occurrence of soil seed banks and factors influencing their distribution, abundance and viability and seed dispersal
- effects of flow on seed germination.

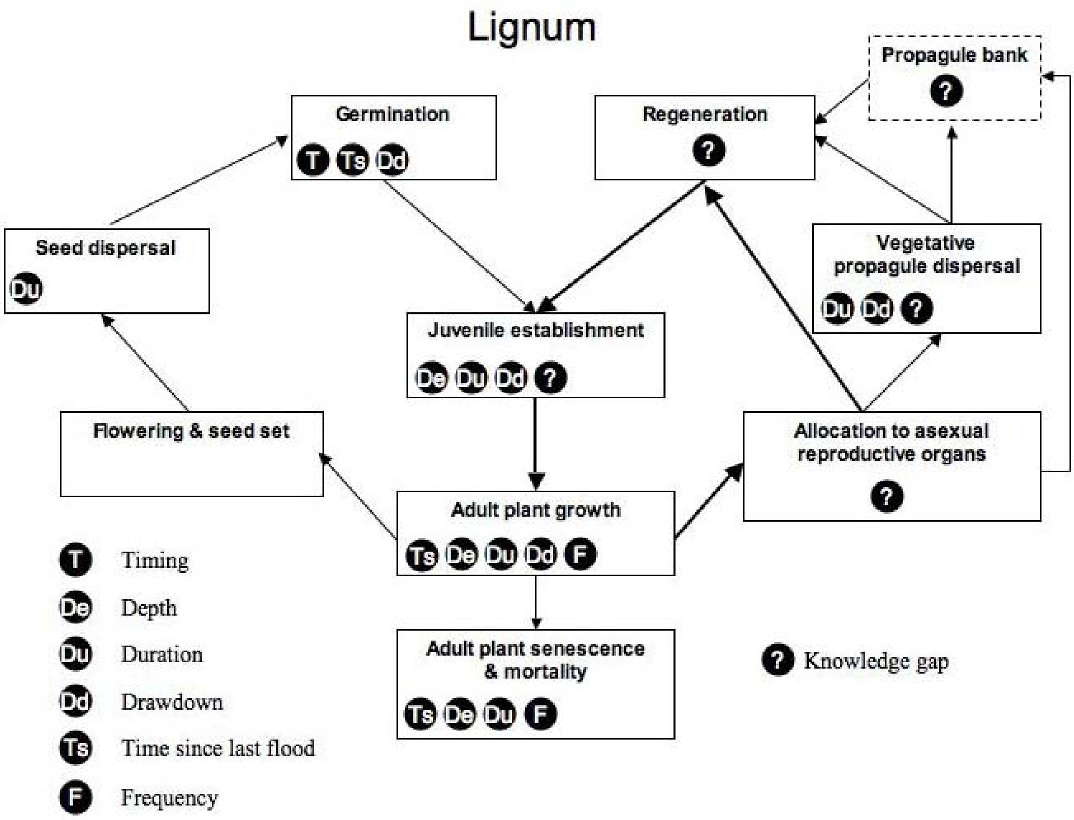

Figure 5: Conceptual model of effects of key flood attributes on major life history processes of lignum (*Muehlenbeckia florulenta*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—lignum conceptual model (Figure 5)

Plant growth, senescence & mortality

Adult lignum plants generally occur in water-ponding areas that flood between 1 in every 3 to 10 years for durations of around 2 to 4 months. Plants may be killed by extended flood durations (Capon, 2003) but this is likely to depend on plant size. Lignum shrubs are extremely drought tolerant.

Vegetative reproduction

Lignum spreads predominantly via rhizomes, stem arching and regeneration from fragments (Chong & Walker, 2005; *personal observations of authors*).

Sexual reproduction

Lignum usually flowers opportunistically in response to rainfall or flooding regardless of the season (Roberts & Marston, 2000; *personal observations of authors*). Large numbers of seeds are produced and these can float for 5 to 25 days (Chong & Walker, 2005). Seeds require light & fluctuating temperatures to germinate. Temperatures of 24°C / 10 °C are optimum (Chong & Walker, 2005). Seedling establishment is usually rare and is favoured by moist rather than submerged conditions (Capon *et al.*, 2009).

Knowledge gaps

- effects of flow on allocation to asexual or sexual reproduction
- effects of flow on vegetative propagule, i.e. fragments, dispersal
- occurrence of vegetative propagule banks and factors influencing their distribution, abundance, viability and regeneration from these
- flow conditions leading to seedling establishment.

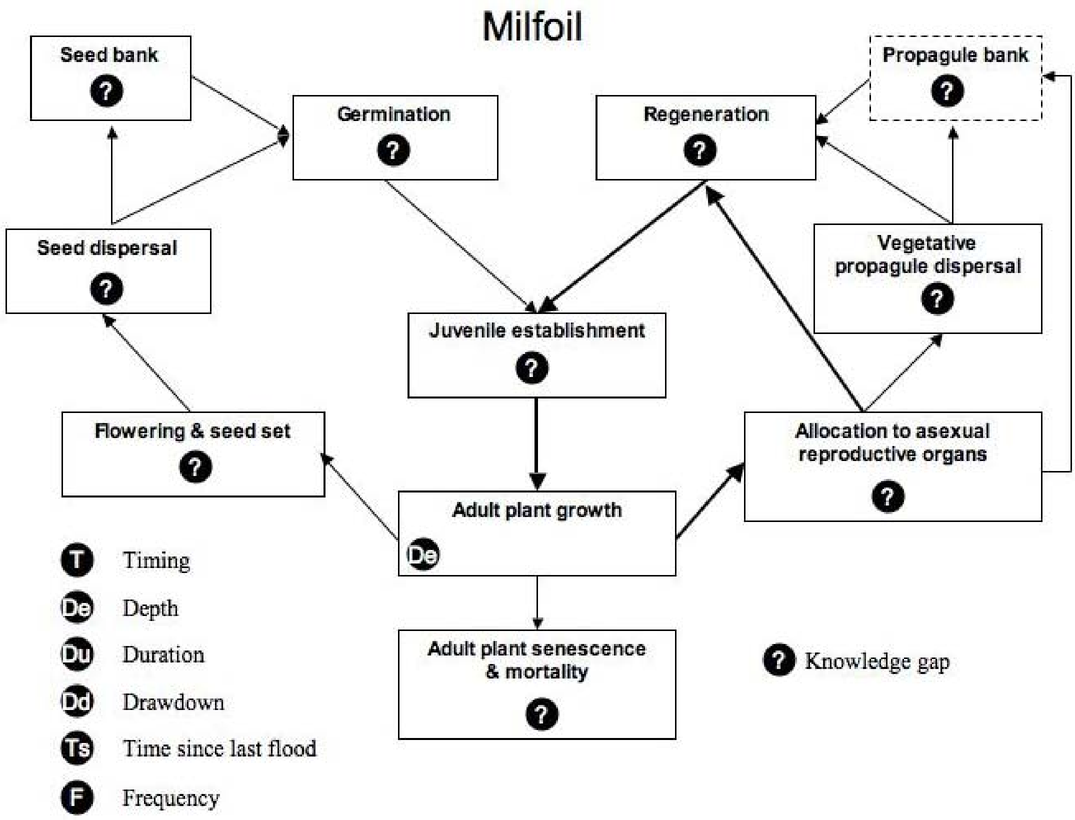

Figure 6: Conceptual model of effects of key flood attributes on major life history processes of milfoil (*Myriophyllum* spp.)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—milfoil conceptual model (Figure 6)

Plant growth, senescence & mortality

Milfoil can tolerate fluctuating water levels and changes its growth form depending on water depth (Roberts & Marston, 2000).

Vegetative reproduction

Asexual reproduction tends to be dominant in milfoil which can regenerate from shoot fragments (Roberts & Marston, 2000) and turions (Cronk & Fennessy, 2001).

Sexual reproduction

Milfoil maintains small but persistent soil seed banks (Abernethy & Wilby, 1999; *personal observation of authors*).

Knowledge gaps

- effects of flow on allocation to asexual or sexual reproduction
- effects of flow on vegetative propagule dispersal and regeneration
- occurrence of vegetative propagule banks and factors influencing their distribution, abundance, viability and regeneration from these
- factors influencing the distribution, abundance and viability of soil seed banks and seed dispersal
- effects of flow on seed germination.

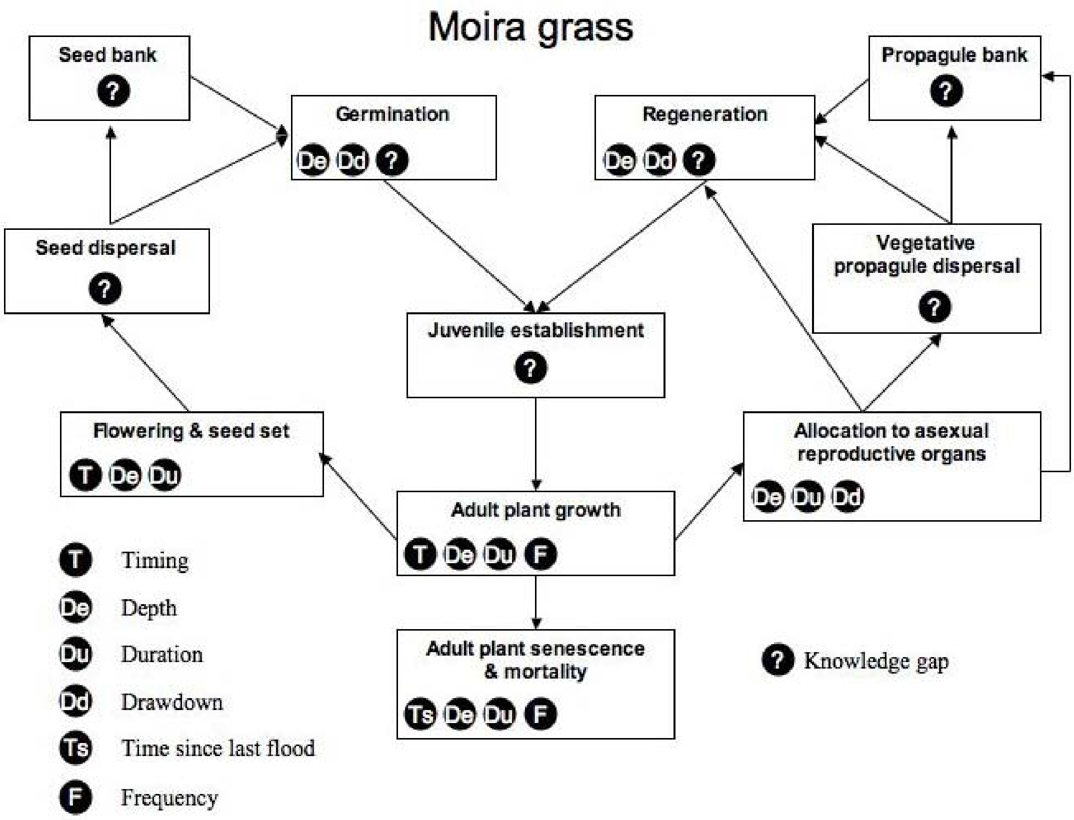

Figure 7: Conceptual model of effects of key flood attributes on major life history processes of Moira grass (*Pseudoraphis spinescens*)

Explanatory notes—Moira grass conceptual model (Figure 7)

Plant growth, senescence & mortality

Growth of Moira grass is favoured by summer flooding with depths between 0.5 to 2m (Ward, 1992; 1996). Optimum flood duration is 7 months with a minimum of 5 and a maximum of 10 months and a flood frequency of 3 out of 4 years (Bren & Gibbs, 1986; Ward, 1996). Moira grass can tolerate drying periods up to 25 months (Bren, 1992).

Vegetative reproduction

Moira grass regenerates from rhizomes and fragments, which may be dispersed short distances, in moist habitats (Roberts & Marston, 2000). Asexual reproduction is triggered by flood recession (Ward, 1992).

Sexual reproduction

Larger individuals of Moira grass flower in summer, approximately one month after stems have emerged from floodwater and prior to floodwater recession (Ward, 1992). Continuous winter/early spring flooding with a minimum depth of 0.5 m is required for optimal flowering and early flooding (June rather than July) may result in poor flowering rates (Ward, 1992). Hydrochoric seed dispersal may occur over short distances and small but persistent soil seed banks may be present (Finlayson *et al.*, 1990).

Knowledge gaps

- relationships of flow to vegetative propagule dispersal
- factors influencing the distribution, abundance, viability and regeneration from vegetative propagule banks
- factors influencing the distribution, abundance and viability of soil seed banks and seed dispersal
- effects of flow on seed germination and seedling establishment.

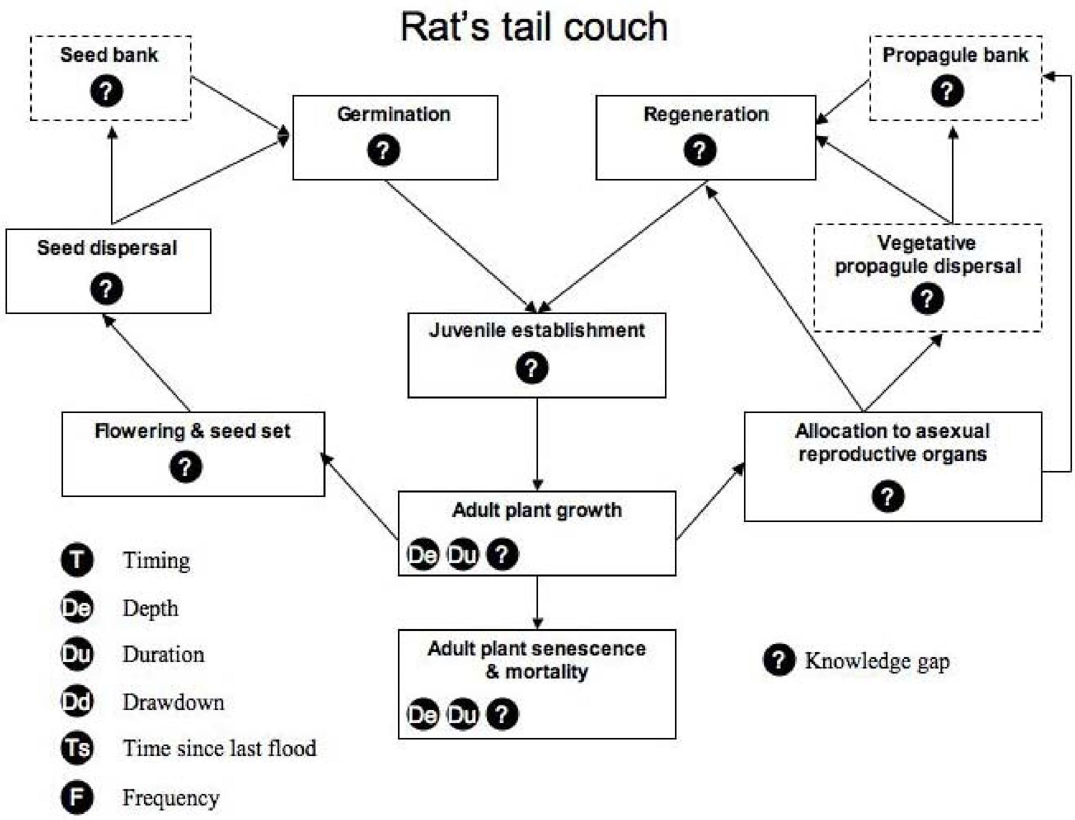

Figure 8: Conceptual model of effects of key flood attributes on major life history processes of rat's tail couch (*Sporobolus mitchellii*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—rat's tail couch conceptual model (Figure 8)

Plant growth, senescence & mortality

Rat's tail couch can tolerate flood depths between 20 to 60 cm and durations up to 73 days along the lower Murray (Blanch *et al.*, 1999).

Vegetative reproduction

Rat's tail couch regenerates from rhizomes.

Knowledge gaps

- effects of flow on plant growth
- effects of flow on allocation to asexual or sexual reproduction
- occurrence of vegetative propagule dispersal and relationships to flow
- occurrence of vegetative propagule banks and factors influencing their distribution, abundance, viability and regeneration from these
- occurrence of soil seed banks and factors influencing their distribution, abundance and viability and seed dispersal
- effects of flow on seed germination and seedling establishment.

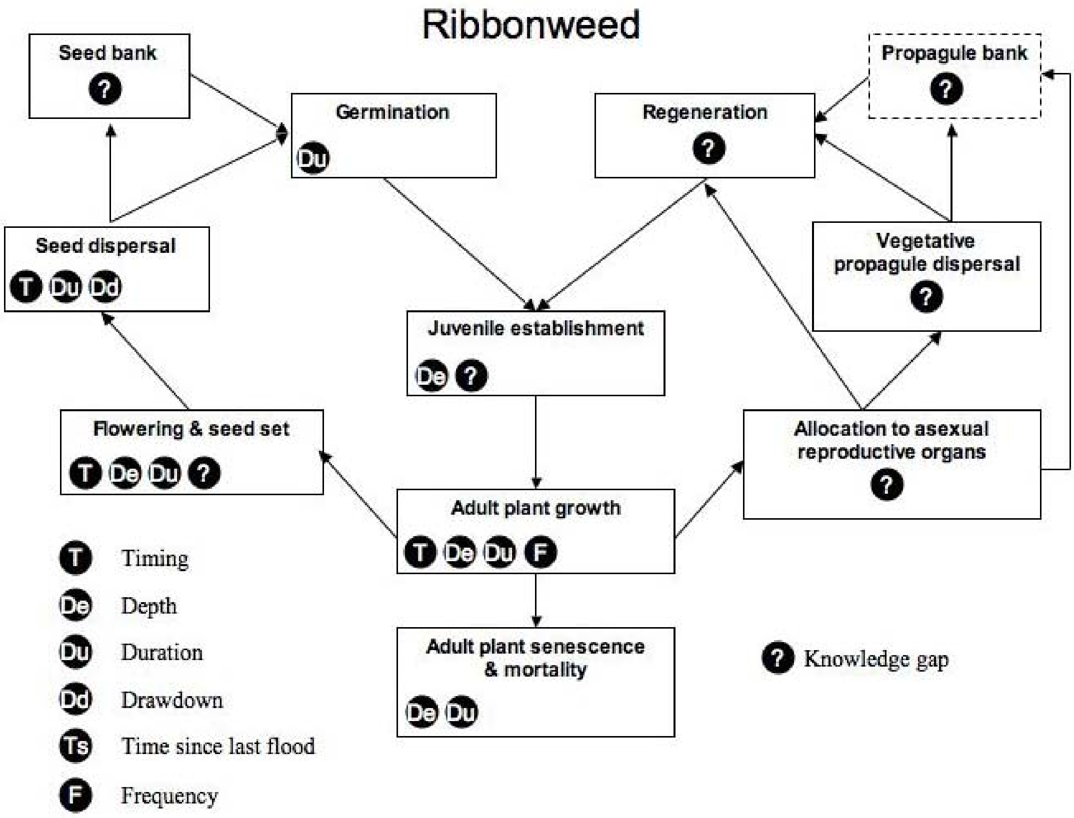

Figure 9: Conceptual model of effects of key flood attributes on major life history processes of ribbonweed (*Vallisneria americana var. americana*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—ribbonweed conceptual model (Figure 9)

Plant growth, senescence & mortality

Ribbonweed grows in shallow and deep waters, its depth distribution determined by light penetration (Blanch *et al.*, 1998). A minimum depth of 1 m may be required during the growing season to allow leaf expansion (Briggs & Maher, 1985). Canopy growth occurs in spring and summer with dieback occurring at the start of winter (Briggs & Maher, 1985). Flood duration needs to be long enough for the build-up of underground storage organs (Roberts & Marston, 2000). Ribbonweed is generally intolerant but cycles of flooding and drying can increase maximum standing crop (Briggs & Maher, 1985).

Vegetative reproduction

Ribbonweed can spread via stolons or regenerate from tubers, fragments or turions (Roberts & Marston, 2000; Cronk & Fennessy, 2001) and vegetative reproduction generally dominates (Jarvis & Moore, 2008).

Sexual reproduction

Ribbonweed plants must be several years old before flowering (Roberts & Marston, 2000), which only occurs during submerged conditions (Ward, 1994) in summer (Catling *et al.*, 1994). Flowering rates vary spatially (Lokker *et al.*, 1997). Wind and animal dispersal of seeds is likely (Catling *et al.*, 1994), but seed pods are also buoyant (Lokker *et al.*, 1997). Small but persistent soil seed banks are maintained (Jarvis & Moore, 2008). Seed germination is rapid (<7 days), with no light requirement (Aston, 1973) and can occur in all seasons (Britton & Brock, 1994). Seedling establishment may be influenced by depth as survival is promoted by high light conditions (Lokker *et al.*, 1997).

Knowledge gaps

- effects of flow on allocation to asexual or sexual reproduction
- effects of flow on vegetative propagule dispersal
- occurrence of vegetative propagule banks and factors influencing their distribution, abundance, viability and regeneration from these
- factors influencing the distribution, abundance and viability of soil seed banks and seed dispersal.

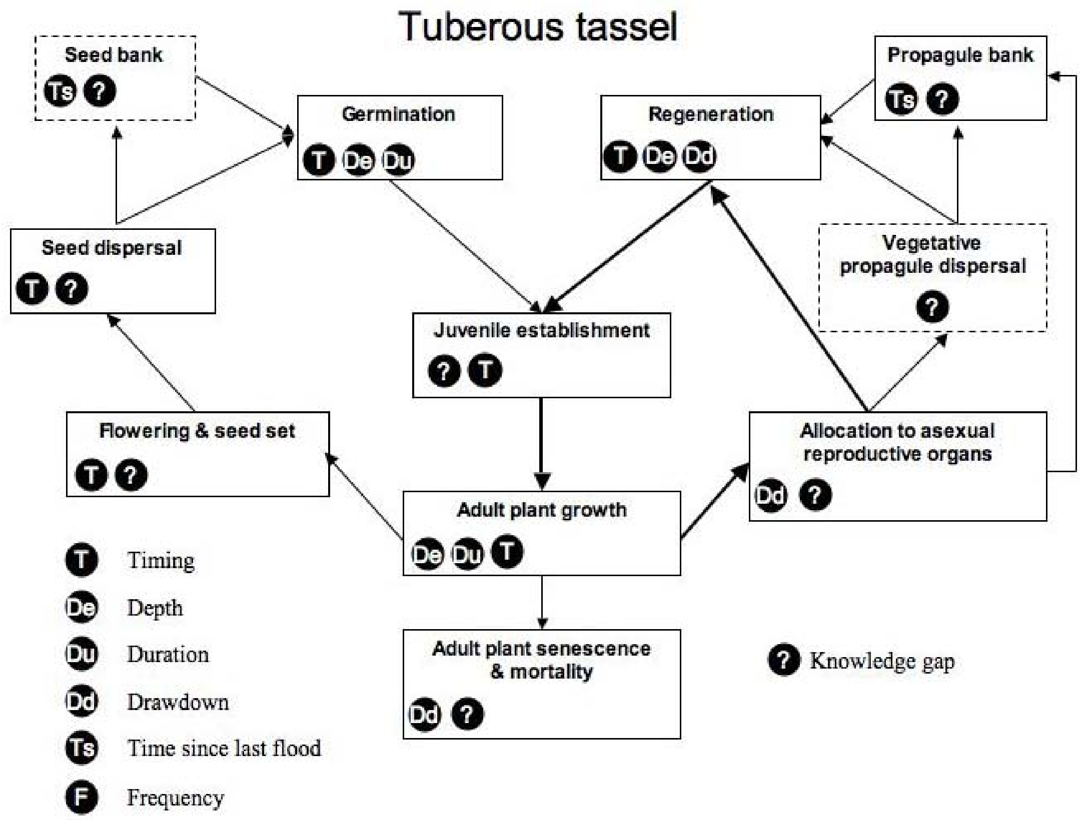

Figure 10: Conceptual model of effects of key flood attributes on major life history processes of tuberous tassel (*Ruppia tuberosa*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—tuberous tassel conceptual model (Figure 10)

Plant growth, senescence & mortality

Ruppia tuberosa is an annual species of ephemeral saline habitats (Jacobs & Brock, 1982). The growing season commences in late autumn-winter and plants die off in summer-autumn (Paton, 2005). Brock (1982b) found that the growth peak for this species was September, approximately 2 months after germination. Regeneration is from both seed and vegetative propagules (turions).

Vegetative reproduction

Vegetative reproduction is important for the annual regeneration of this species. Lateral spread is by rhizomes and survives the dry season as turions (Jacobs & Brock, 1982). Turions are produced from late spring and summer (Paton, 2005) and readily detach from the parent plant (Brock, 1982b).

Sexual reproduction

Seeds are produced in late spring-summer and are important for regeneration the following growing season (Paton, 2005). Seed are tolerant of desiccation (Brock, 1982b). Germination from seed can be rapid and occurs in a "pulse" that may reduce competition with other taxa (Porter, 2007). Germination is dependent upon saline water or breakage of the seed coat (Brock, 1982b).

Knowledge gaps

Ruppia tuberosa populations have been in decline in the southern Coorong since 1998 (Paton, 2005). Salinity changes may be contributing to this decline but other factors could also be contributing (Paton, 2005). As identified by Lamontagne *et al.*, (2004), a better understanding of the water balance of the LLCMM Icon Site (e.g. better gauging of freshwater inflows, measurement of flows through the barrages, better modelling of lake water levels) is essential for producing realistic habitat models that can be used to develop management strategies for *R. tuberosa*. Paton (2005) emphasised the need for research on relationships between salinity, water levels and light availability so that maximum benefit can be obtained from environmental water allocations, when available.

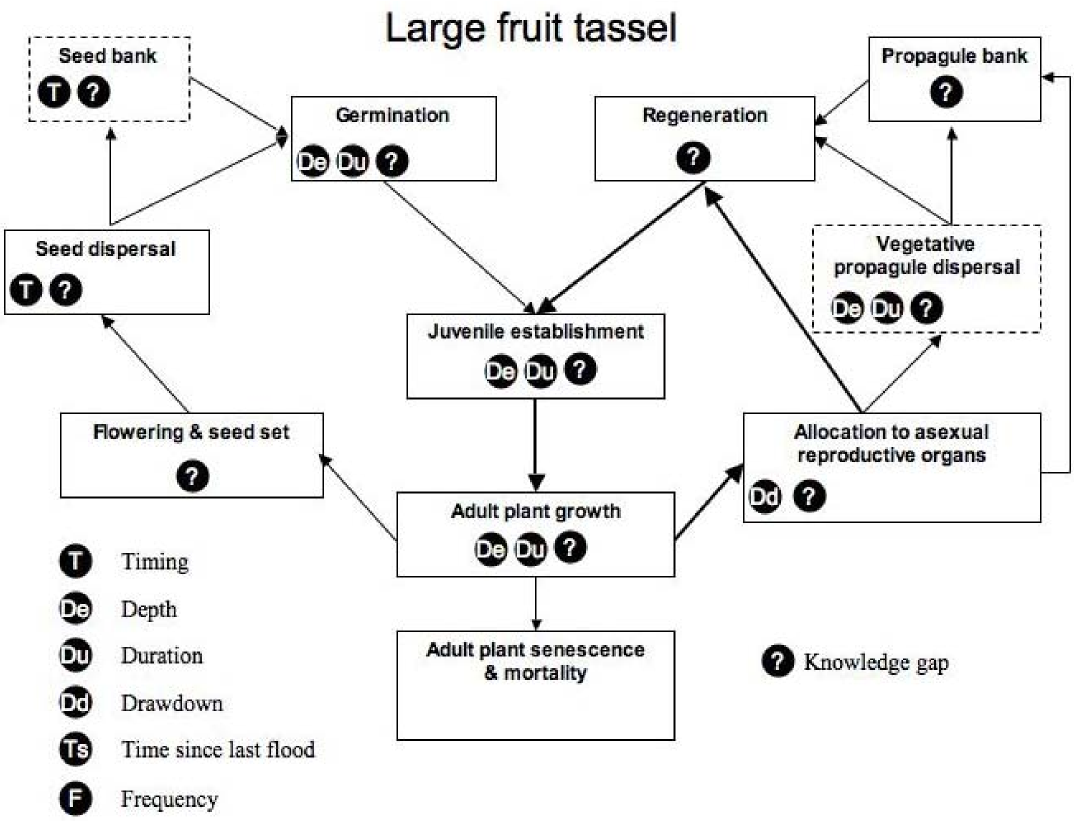

Figure 11: Conceptual model of effects of key flood attributes on major life history processes of large fruit tassel (*Ruppia megacarpa*)

(N.B. Dashed lines indicate uncertainty about occurrence of life history stage.)

Explanatory notes—large fruit tassel conceptual model (Figure 11)

Plant growth, senescence & mortality

Ruppia megacarpa is a perennial species of brackish to hypersaline permanent waters (Jacobs & Brock, 1982). Flowering occurs from November to March (Brock, 1982b). Growth shows a distinct seasonal pattern with relatively low biomass during winter and peak biomass occurring in summer (Brock, 1982b).

Specific flow requirements for growth are not known. However, permanent water is required for survival as this species is intolerant of desiccation (Jacobs & Brock, 1982). Highly variable flow regimes and flow regimes that produce deleterious changes in the abiotic environment may be detrimental to the growth of *R. megacarpa*.

Vegetative reproduction

Asexual reproduction via rhizomes and rooting from stem nodes is the principal method of reproduction (Brock, 1982b). Vegetative parts are intolerant of desiccation (Jacobs & Brock, 1982). Perennating organs such as turions are not produced (Brock, 1982b). Vegetative fragments are readily dispersed but establishment rates have not been reported. Congdon & McComb (1980) reported that black swans ingested large amounts of *Ruppia* (presumably *R. megacarpa*) and it passed through the digestive tract apparently undigested. Dispersal by waterfowl may therefore be important but the viability of the material was not reported.

Sexual reproduction

Sexual reproduction is important for dispersal but not for local spread (Jacobs & Brock, 1982). Germination of seed may not occur in stable habitats that are conducive to vegetative growth (Brock, 1982a). There doesn't appear to be specific hydrologic triggers for seed germination but seed dormancy can be broken by freshwater (Brock, 1982a).

Knowledge gaps

Knowledge gaps identified for *Ruppia tuberosa* (tuberous tassel) are relevant to *R. megacarpa*. Other knowledge gaps include:

- effects of flow on asexual and sexual reproduction;
- tolerance of *R. megacarpa* to flow variability (e.g. does infrequent exposure cause rhizome death?);
- factors affecting viability of rhizome or stem fragments.

7.4 Conceptual models for selected vegetation communities

Figure 12 presents a generic conceptual model outlining the effects of key flood attributes on major processes shaping floodplain understorey and aquatic vegetation dynamics. Specific floodplain understorey and aquatic vegetation communities were selected on the basis of their significance, dominance and prevalence across The Living Murray icon sites as well as the availability of relevant information. These models are presented in Figures 13 to 21. The communities selected were:

- ephemeral herb lands
- reed-beds
- giant rushlands
- Moira grass plains
- lignum shrublands
- river red gum forests & woodlands
- black box woodlands
- weir pools
- submerged vegetation of LLCMM.

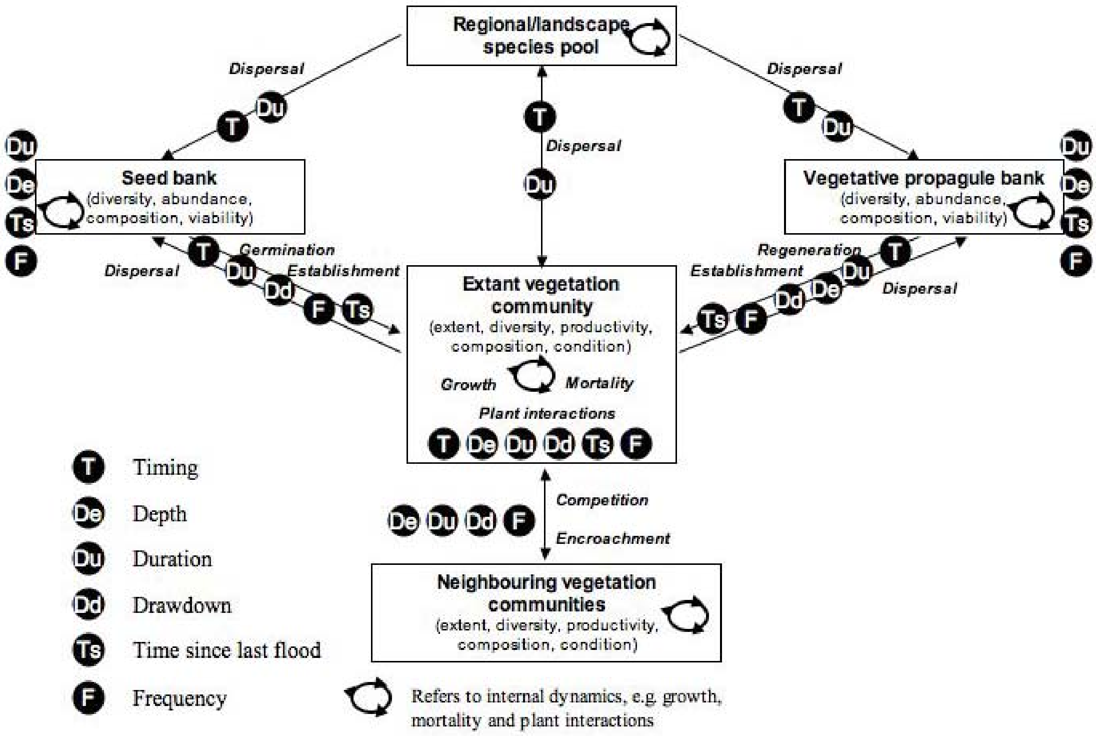

Figure 12: Conceptual model of effects of key flood attributes on vegetation dynamics in a generic floodplain understorey/aquatic vegetation community

Explanatory notes—generic floodplain understorey/aquatic vegetation community conceptual model (Figure 12)

Extant vegetation: extent, character & condition

Processes influencing vegetation community composition and structure, e.g. plant growth, mortality, competition and facilitation, etc., can be shaped by the full suite of flood attributes considered here and the importance of these will depend on the constituent species of a particular community. Flood timing can affect which species will respond with growth and by how much, as a result of seasonal differences in growth rates. Flood depth and duration will also affect the range of species for which growth is favoured as well as the magnitude of growth responses. The extent and magnitude of plant senescence and mortality will also be influenced by flood depth and duration. Time since last flood event and flood frequency will play an important role in shaping the initial floristic composition of a community present to respond to flooding. The composition and abundance of viable propagules that have been dispersed into a community from elsewhere are likely to be influenced by flood timing and duration. The significance and outcome of plant interactions, i.e. competition and facilitation, may also be determined by the time since last flood event and flood frequency, since these are often governed by soil moisture levels (*current research of authors*).

Propagule banks: extent, character & condition

The distribution, abundance, composition and viability of both seed and vegetative propagule banks are likely to vary in relation to flood frequency as a result of flood-driven differences in opportunities for propagule bank replenishment, e.g. germination and dispersal, and depletion, e.g. germination, granivory, rotting etc.. Areas of permanent and deep flooding, for instance, are likely to have smaller, less diverse soil seed banks (Capon & Brock, 2006). Flood duration and timing will also play a role in determining which propagules and how many are dispersed into propagule banks from local or external vegetation communities.

Vegetation regeneration

Contributions to the extant vegetation of soil seed and vegetative propagule banks, as well as propagules dispersed from elsewhere, will be influenced by the effects of flooding on processes of germination, regeneration and establishment. Typically, the contribution of soil seed banks the extant vegetation is governed by flood duration, depth, frequency and timing (Casanova & Brock, 2000; Capon, 2007).

Effects of neighbouring communities

Neighbouring communities may influence the vegetation by providing a source from which species may encroach. Encroachment may occur as a result of changes to conditions, e.g. flood depth, duration or frequency, that result in habitat conditions suited to species from neighbouring communities, i.e. niche expansion, or alter competitive relationships enabling species to move into new habitats.

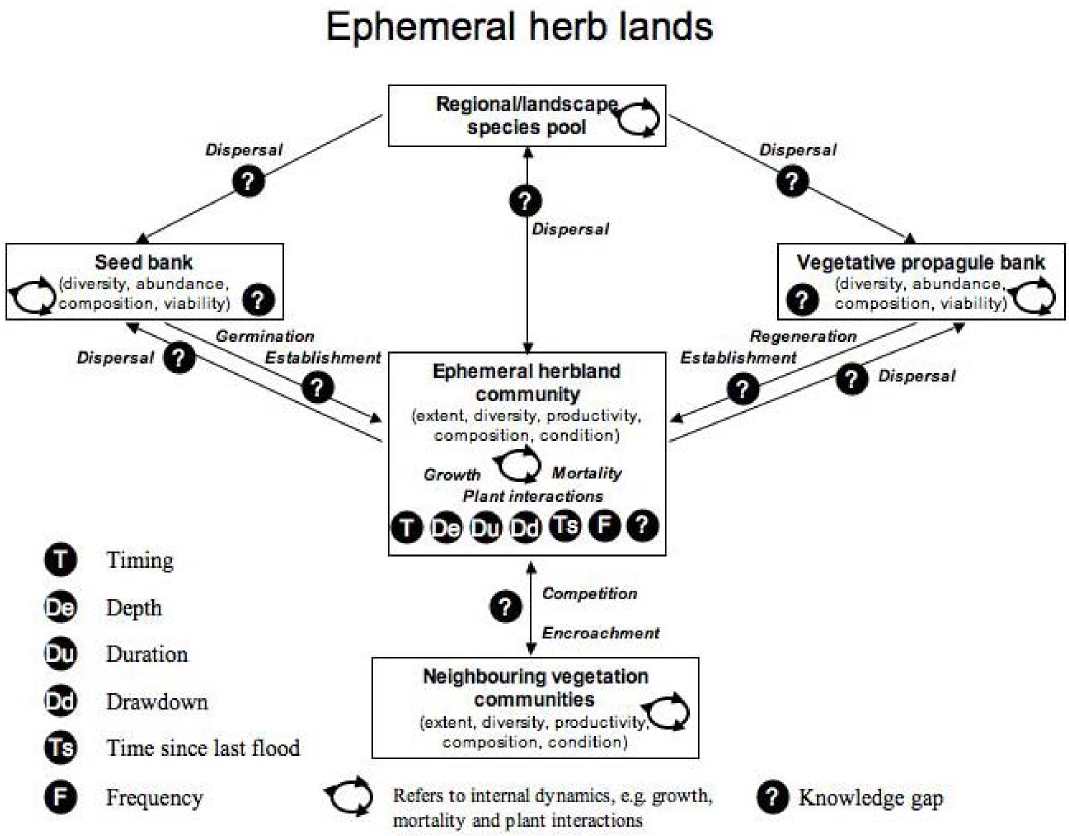

Figure 13: Conceptual model of effects of key flood attributes on vegetation dynamics in ephemeral herb lands

Explanatory notes—ephemeral herb lands conceptual model (Figure 13)

Extant vegetation: extent, character & condition

Ephemeral herb lands occur within the icon sites in frequently inundated floodplain areas and wetlands, e.g. lake beds in the Hattah Lakes. These vegetation communities are likely to be highly variable temporally and will shift in composition, diversity and productivity in relation to hydrologic conditions. Flooding will lead to mortality of flood-intolerant taxa that may colonise these areas during dry periods, e.g. chenopod shrubs and sub-shrubs on lake beds, although the extent of this effect will depend on flood depth, duration and the time since last flood. Submergence will also trigger the germination and establishment of aquatic plants, e.g. milfoil and ribbonweed, either from propagules stored in propagule banks or seeds and vegetative fragments arriving as a result of dispersal by floodwaters, wind or animals, e.g. waterbirds. Following recession of floodwaters, vegetation communities comprising annual and short-lived perennial forbs and monocots are likely to develop. Flood attributes including frequency, timing, depth, duration and rate of drawdown are typically the key factors shaping the composition and structure of ephemeral herb lands. The time since last flood event will determine the presence and abundance of flood-dependent and flood-responsive taxa. In general, vegetation diversity may be expected to be greatest in areas of intermediate flood frequency, depth and duration.

Propagule banks: extent, character & condition

Soil seed banks are likely to be the dominant source of propagules for plant regeneration in ephemeral herb lands (e.g. Capon & Brock, 2006; James *et al.*, 2007). Some preliminary investigations into persistent soil seed banks conducted in Hattah Lakes, indicate the presence of reasonably diverse and abundant seed banks that vary between lakes in relation to flood history (EPA and MDFRC, 2008).

Vegetation regeneration

The germination and establishment of vegetation communities developing both during flooding and following drawdown, are likely to be influenced strongly by flood frequency, timing, duration, depth and rate of drawdown. Regeneration is likely to occur primarily from persistent soil seed banks.

Effects of neighbouring communities

Reductions in flood frequency and increased durations of dry periods may result in the encroachment of ephemeral herb lands by taxa previously restricted to higher elevations, e.g. lignum or chenopod shrubs and sub-shrubs. Increased flood frequency, depth and duration may also lead to the invasion of ephemeral herb lands by communities such as giant rush lands or cumbungi stands.

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites
- effects of flood attributes on vegetation character following drawdown in icon sites
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites
- specific flow conditions leading to encroachment of ephemeral herb lands by neighbouring communities, e.g. cumbungi, giant rushlands.

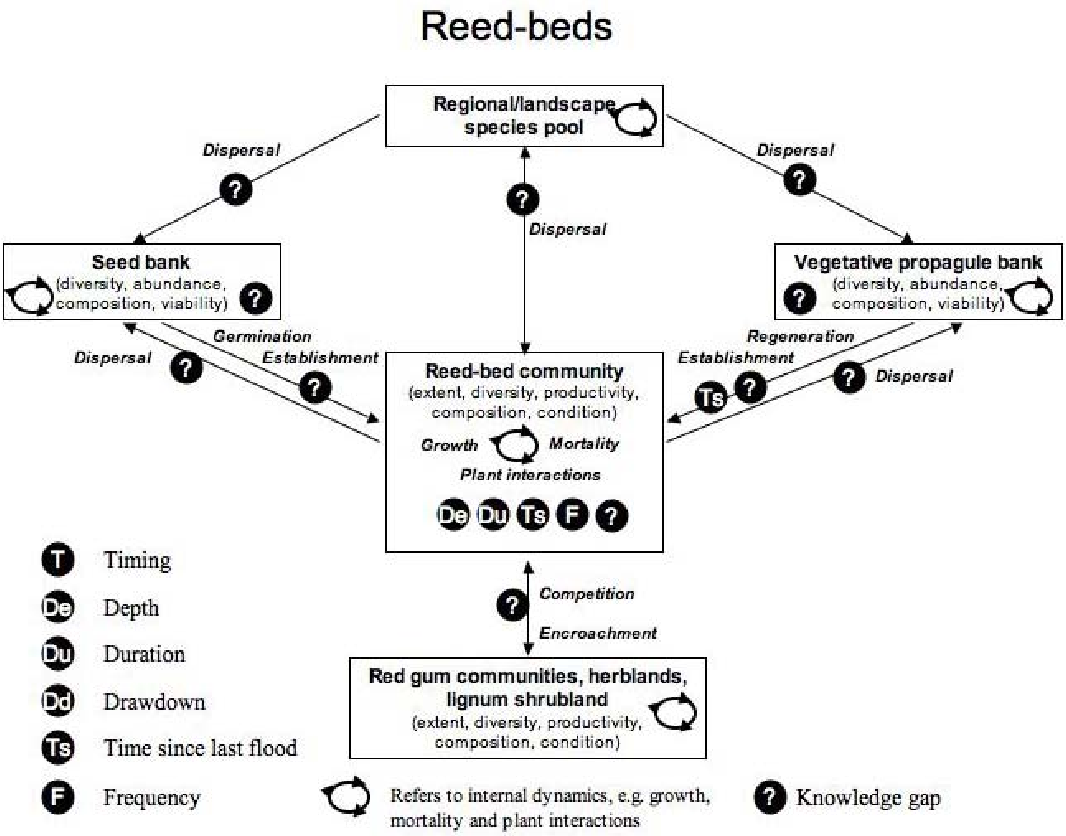

Figure 14: Conceptual model of effects of key flood attributes on vegetation dynamics in reed-beds

Explanatory notes—reed-beds conceptual model (Figure 14)

Extant vegetation: extent, character & condition

Common reed reed-beds occur in all of The Living Murray icon sites, either as the dominant perennial vegetation type in an area or as understorey to river red gum communities. In riparian areas of the lower Murray, reed-beds occur where banks flood between 80 and 225 days of the year to a depth less than 60 cm (Blanch *et al.*, 1999). Reed-beds in the icon sites are likely to support a variety of other understorey species including forbs, grasses, sedges, rushes and sub-shrubs, which will vary in presence and abundance depending on hydrological and seasonal conditions. Reed-beds also often occur in conjunction with cumbungi. The extent, growth and vigour of common reed itself will be closely related to flood depth, duration and frequency as depicted in Figure 2.

Propagule banks: extent, character & condition

Reed-beds within the icon sites are likely to have quite diverse and abundant soil seed banks containing a high proportion of annual and ephemeral forbs (*based on observations in Yanga NP*). Common reed itself may also maintain rhizome banks, which may persist for several years, from which plant regeneration may occur (see Fig. 2).

Vegetation regeneration

The time since last flood event will influence regeneration of common reed from buried rhizomes as these will have a limited life span.

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites
- effects of flood attributes on vegetation character following drawdown in icon sites
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites
- factors influencing spatial thresholds with neighbouring vegetation communities.

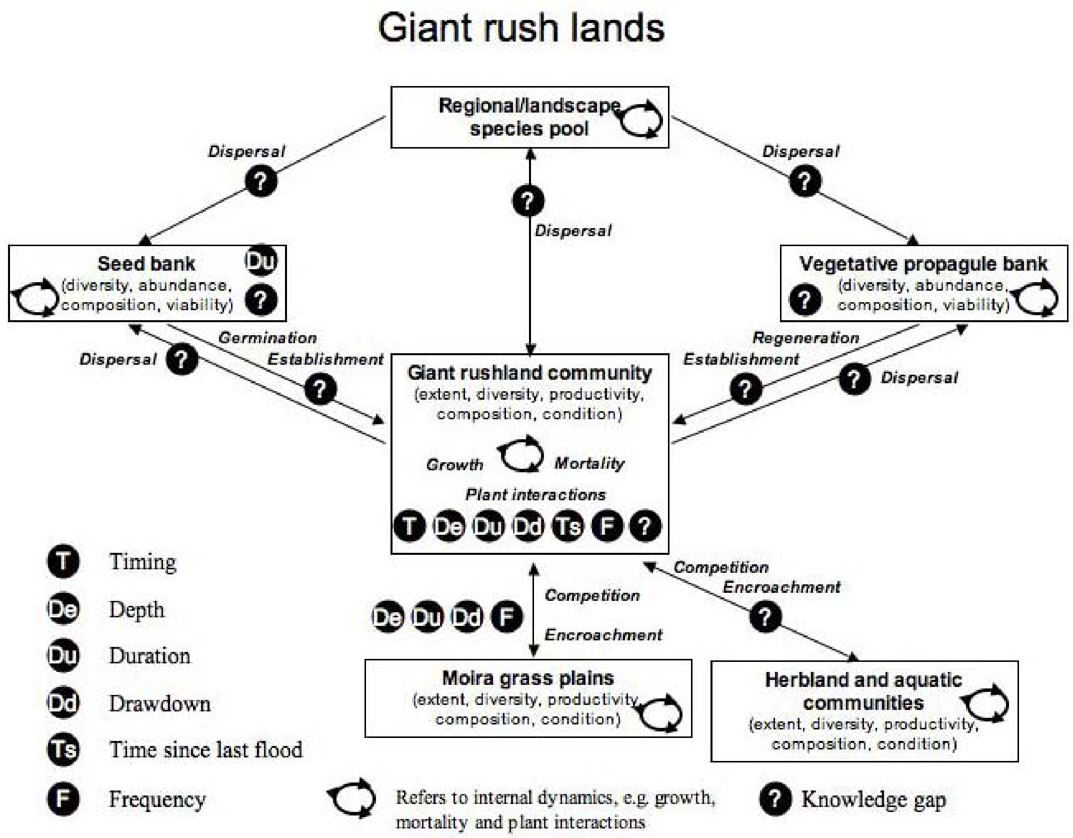

Figure 15: Conceptual model of effects of key flood attributes on vegetation dynamics in giant rushlands

Explanatory notes—giant rushlands conceptual model (Figure 15)

Extant vegetation: extent, character & condition

Extensive stands dominated by giant rush occur in the Barmah–Millewa Forest and to a lesser extent, in Chowilla and Hattah Lakes. The extent, growth and vigour of giant reed itself will be closely related to flood depth and duration as depicted in Figure 4. In northern Victoria, giant rushlands occur where winter-spring flooding lasts between 6 and 11 months and is less than 1.5 m deep (Ward, 1996).

Propagule banks: extent, character & condition

Seeds of giant rush are unlikely to persist in deeply or permanently flooded areas (MDBC, 2005a).

Effects of neighbouring communities

Giant rushlands have expanded in northern Victoria where flood frequency has declined and flood durations have been reduced from an average of 8.6 to 3.6 months (Leitch 1989 in Roberts & Marston, 2000).

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites
- effects of flood attributes on vegetation character following drawdown in icon sites
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites.

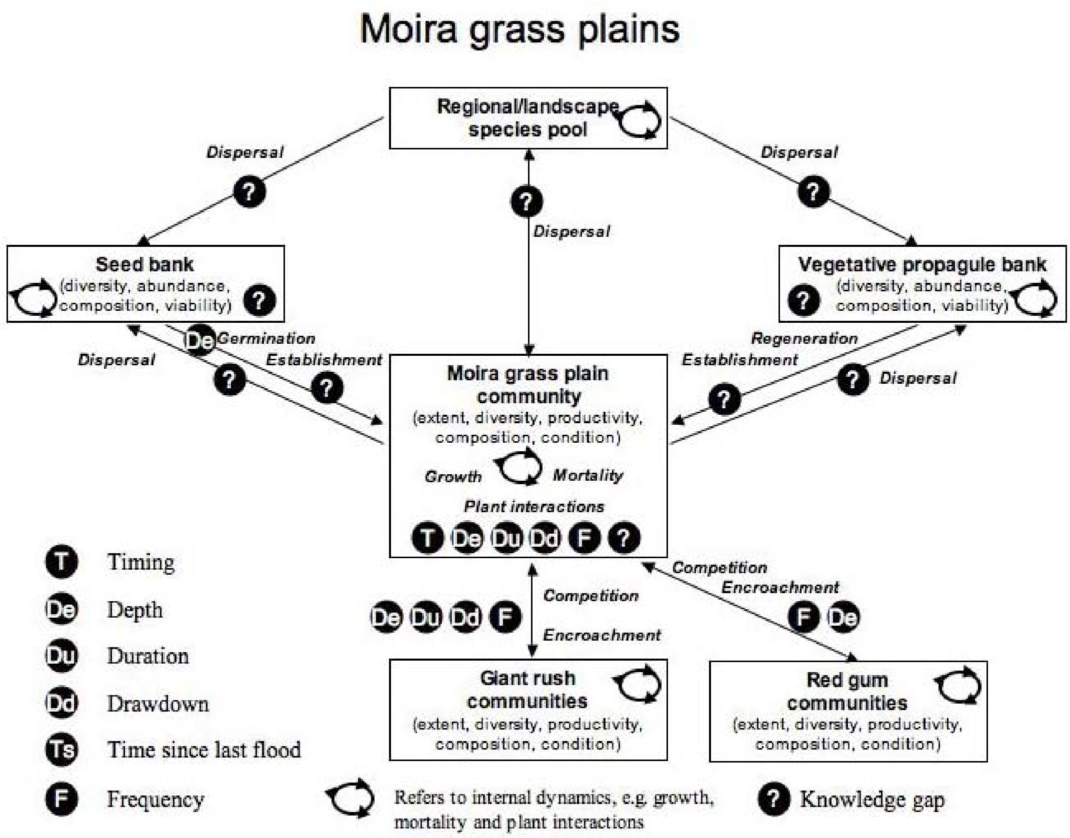

Figure 16: Conceptual model of effects of key flood attributes on vegetation dynamics in Moira grass plains

Explanatory notes—Moira grass plains conceptual model (Figure 16)

Extant vegetation: extent, character & condition

Moira grass plains occur in the Barmah–Millewa, Gunbower Forests, Chowilla, Hattah Lakes and riparian and floodplain areas of the River Murray. The extent, growth and vigour of Moira grass itself will be closely related to flood timing, depth, duration and frequency as depicted in Figure 7. In Victoria, Moira grass plains occur where flooding occurs in 3 out of 4 years, lasts between 7 and 10 months and is between 0.5 and 2 m deep (Bren & Gibbs, 1986; Ward, 1996). Rapid growth is promoted by summer flooding (Roberts & Marston, 2000).

In Barmah, continuous late winter-early spring flooding with recession prior to summer is considered ideal flood timing (Ward, 1992). In competitive interactions with Moira grass, milfoil appears to be favoured by flood durations exceeding mid-summer (Ward, 1992). Moira grass plains in Barmah can persist where dry periods intervening floods are as long as 25 months (Bren, 1992).

Propagule banks: extent, character & condition

Moira grass itself may maintain small but persistent soil seed banks (Finlayson *et al.*, 1990).

Vegetation regeneration

Flood depth is likely to influence germination of Moira grass from seed bank with establishment probably favoured by shallow flood depths or moist conditions (Finlayson *et al.*, 1990).

Effects of neighbouring communities

In Barmah Forest, Moira grass plains are being encroached on by river red gum communities in higher elevations and giant rush lands in lower elevations. This river red gum invasion is attributed to reductions in flood frequency (Bren, 1992). Increased frequency of shallow floods, however, is thought to be responsible for the expansion of giant rush (MDBC, 2005a).

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites (some knowledge in Barmah)
- effects of flood attributes on vegetation character following drawdown in icon sites (some knowledge in Barmah)
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites.

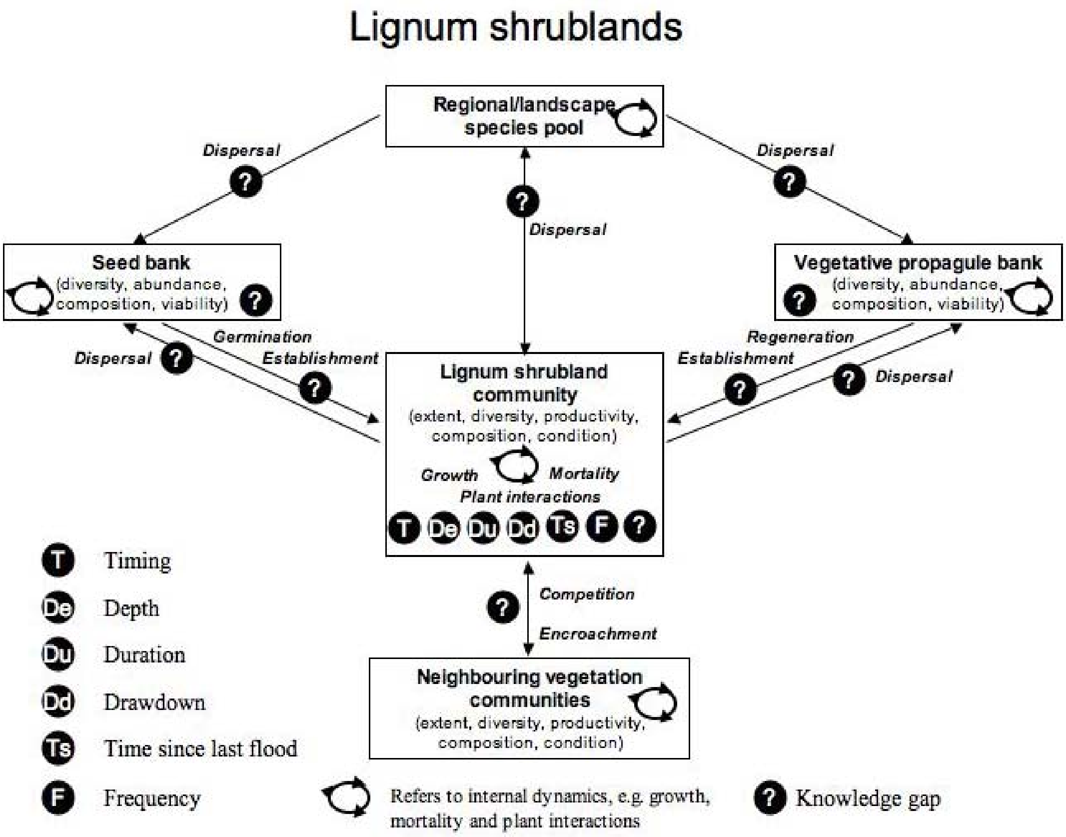

Figure 17: Conceptual model of effects of key flood attributes on vegetation dynamics in lignum shrublands

Explanatory notes—lignum shrublands conceptual model (Figure 17)

Extant vegetation: extent, character & condition

Lignum shrublands occur in the Barmah–Millewa Forest, Chowilla Floodplain, Hattah Lakes and riparian and floodplain areas of the River Murray icon sites. The extent, growth and vigour of lignum itself will be closely related to flood depth, duration, rate of drawdown, frequency and the time since last flood event as depicted in Figure 5. In general, lignum shrublands occur in areas that flood once in every 3 to 10 years (Roberts & Marston, 2000) as lignum shrubs are likely to be killed by deep or prolonged periods of flooding (Capon, 2003). Lignum shrublands in more frequently flooded areas are characterised by large (~3 m tall) clumps while in infrequently flooded areas, many small scattered individuals occur (Capon *et al.*, 2009).

Lignum shrublands often support diverse and productive understorey communities that fluctuate in composition and structure in relation to hydrological conditions. They may comprise aquatic plants, e.g. milfoil and ribbonweed, during periods of submergence and a range of ephemeral and annual forbs and monocots following floodwater recession. Facilitation of understorey plants by lignum shrubs during dry periods may play a significant role in maintaining plant community diversity between floods as shrubs are likely to ameliorate harsh conditions through the provision of shade and increased soil moisture and nutrient content (*unpublished results of authors*).

Propagule banks: extent, character & condition

Soil seed banks in lignum shrublands are often highly diverse and abundant (James *et al.*, 2007). Lignum seeds, however, do not form persistent soil seed banks (Chong & Walker, 2005). Propagule banks comprising rhizomes and fragments may be present (*unpublished results of authors*).

Vegetation regeneration

Recruitment of lignum seedlings or juvenile clones is likely to be favoured by moist rather than submerged conditions (Capon *et al.*, 2009). Germination of forbs and monocots from soil seed banks will be influenced by flood depth, duration, timing and rate of drawdown.

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites (some knowledge in Barmah)
- effects of flood attributes on vegetation character following drawdown in icon sites (some knowledge in Barmah)
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites
- factors influencing spatial thresholds with neighbouring vegetation communities.

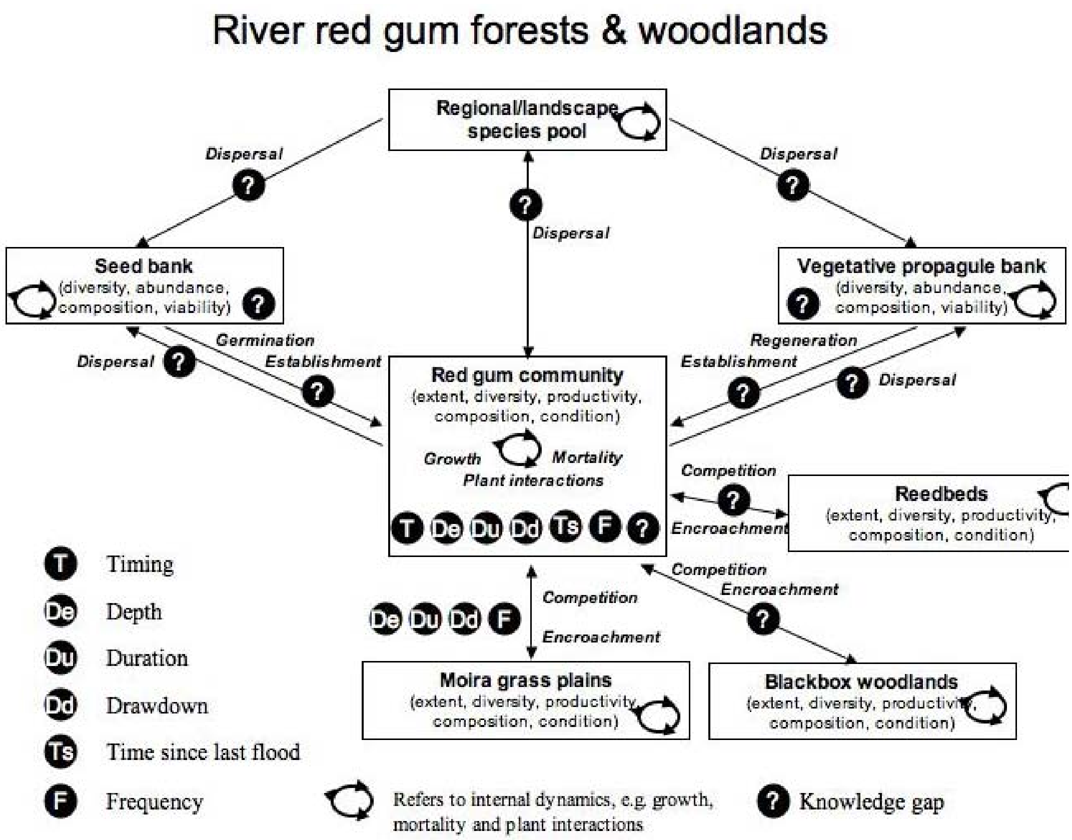

Figure 18: Conceptual model of effects of key flood attributes on vegetation dynamics in river red gum forests and woodlands

Explanatory notes—river red gum forest & woodlands conceptual model (Figure 18)

Extant vegetation: extent, character & condition

River red gum communities are significant in all of the icon sites except the LLCMM. Understorey communities may include areas of lignum shrubland and common reed-beds, but are usually dominated by mixtures of forbs and monocots that shift in composition and structure both temporally and spatially in relation to hydrological conditions. Frequently flooded areas are likely to support more flood dependent and flood tolerant species, while rarely flooded areas my be dominated by terrestrial grass, e.g. wallaby grass and kangaroo grass in Gunbower (Cooling *et al.*, 2002), or shrubs and sub-shrubs, often chenopods.

Propagule banks: extent, character & condition

River red gum communities in the region often have highly diverse and abundant soil seed banks comprising forbs, sedges, rushes and grasses (*unpublished results of authors*). The abundance, diversity and composition of soil seed banks are likely to shift in relation to flood history.

Vegetation regeneration

Regeneration of understorey communities in river red gum woodlands and forests is likely to rely substantially on germination from persistent soil seed banks which will be influenced by flood timing, depth, duration, rate of drawdown and frequency.

Effects of neighbouring communities

River red gum communities are expanding into lower elevations in the Barmah Forest as a result of reductions in flood frequency. Invasion of river red gum communities by species from neighbouring black box woodlands or upland communities is also likely to occur during dry periods.

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites
- effects of flood attributes on vegetation character following drawdown in icon sites
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites.

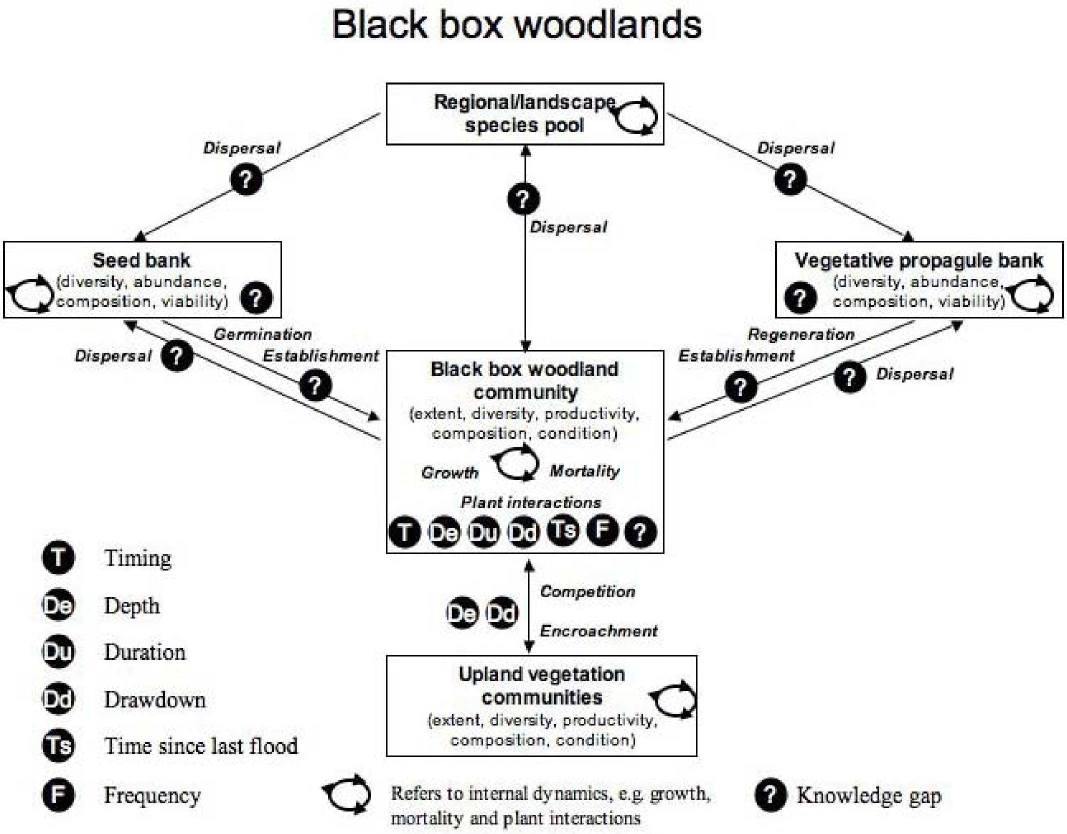

Figure 19: Conceptual model of effects of key flood attributes on vegetation dynamics in black box woodlands

Explanatory notes—black box woodlands conceptual model (Figure 19)

Extant vegetation: extent, character & condition

Black box woodlands occur in all of the icon sites except the LLCMM. Understorey communities are typically dominated by terrestrial grasses and chenopod shrubs and sub-shrubs, e.g. *Atriplex* spp. and *Sclerolaena* spp.. Variable mixtures of understorey forbs and other monocots may also occur depending on hydrological conditions. Large floods that inundate black box woodlands are likely to result in mortality of some shrubs and sub-shrubs and the temporary establishment of annual and ephemeral forbs and monocots from the soil seed bank following the recession of flood waters depending on flood timing, depth, duration and rate of drawdown. Flood frequency and the time since last flood event will be important determinants of the relative proportions in the flora of terrestrial grass and shrubs versus flood responsive plants.

Propagule banks: extent, character & condition

Black box communities in the area are likely to have moderately abundant and diverse soil seed banks (*unpublished results of authors*).

Vegetation regeneration

During and following floods, regeneration of understorey communities in black box woodlands may rely on germination from persistent soil seed banks which will be influenced by flood timing, depth, duration, rate of drawdown and frequency. Regeneration of most shrubs and sub-shrubs and some terrestrial grasses, however, will probably depend on propagule dispersal or vegetative recruitment since these species do not appear to rely on soil seed banks for persistence (Williams *et al.*, 2008; Capon & Brock, 2006).

Knowledge gaps

- degree of natural variability in vegetation composition and structure in icon sites, i.e. limits of acceptable change
- effects of flood attributes on vegetation character during submergence in icon sites
- effects of flood attributes on vegetation character following drawdown in icon sites
- factors influencing the presence, character and condition of propagule banks in icon sites
- factors influencing propagule dispersal
- factors influencing vegetation regeneration in icon sites.

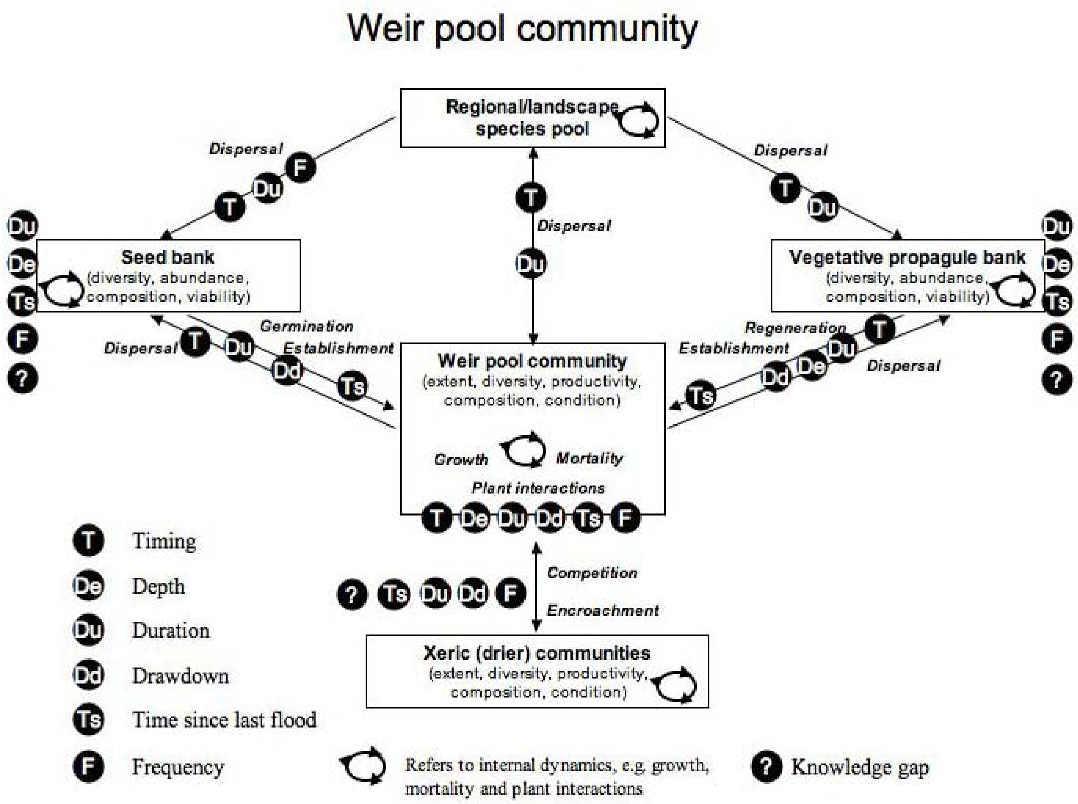

Figure 20: Conceptual model of effects of key flood attributes on vegetation dynamics in weir pools

Explanatory notes—weir pool community conceptual model (Figure 20)

Extant vegetation: extent, character & condition

A diverse aquatic and semi-aquatic flora comprising submerged, emergent and floating species is associated with weir pools in the River Murray. The vegetation of weir pools is strongly influenced by the variability and extent in water level fluctuations (Blanch *et al.*, 1999) and hence while the species composition may reflect that which would have existed prior to flow regulation the distribution of vegetation across the river channel has undoubtedly changed.

Propagule banks: extent, character & condition

Many of the species occurring in the weir pools of the Murray channel (Blanch *et al.*, 1999) spread by vegetative means. It is likely that the propagule bank is extensive and representative of many of the taxa present i.e. representative of submerged, floating and emergent taxa. However, reductions in water level fluctuations may have reduced the areal extent of the aquatic vegetation propagule bank.

Vegetation regeneration

Many of the species reported by Blanch *et al.* (1999) as occurring in weir pools reproduce asexually and therefore have the ability to respond rapidly to environmental changes (e.g. through rhizome or stolon extension). However, species that fail to reproduce sexually and establish seed banks as a result of the modified hydrologic regime may have limited capacity to re-establish in the event of floods that remove above-ground biomass. For example, for some species such as *Myriophyllum* receding water levels can trigger flowering (Orchard, 1985).

Effects of neighbouring communities

The reductions in water level variation in weir pools may allow species representative of drier (xeric) habitats to move downbank and occupy positions lower on the elevation gradient. This includes weedy species which have been associated with drier habitats in the River Murray (Margules *et al.*, 1990).

Knowledge gaps

Blanch *et al.* (1999) examined the influence of water levels on vegetation associated with weir pools in the River Murray. The authors identified several ways in which their work could be extended. These included:

- extending the work to other weir pools;
- extending the species included (Blanch *et al.* included 26 species in their analyses). This would allow allocation of life history strategies to other species;
- increasing the number of water regime indices;
- investigation of the effects of previous flow history on community resilience.

Other knowledge gaps relevant to this community type include:

- effects of flow on asexual and sexual reproduction;
- relative importance of the flow regime *versus* other factors (e.g. land use, water quality) on the structure of vegetation communities;
- extent and species composition of seed and propagule banks in weir pools.

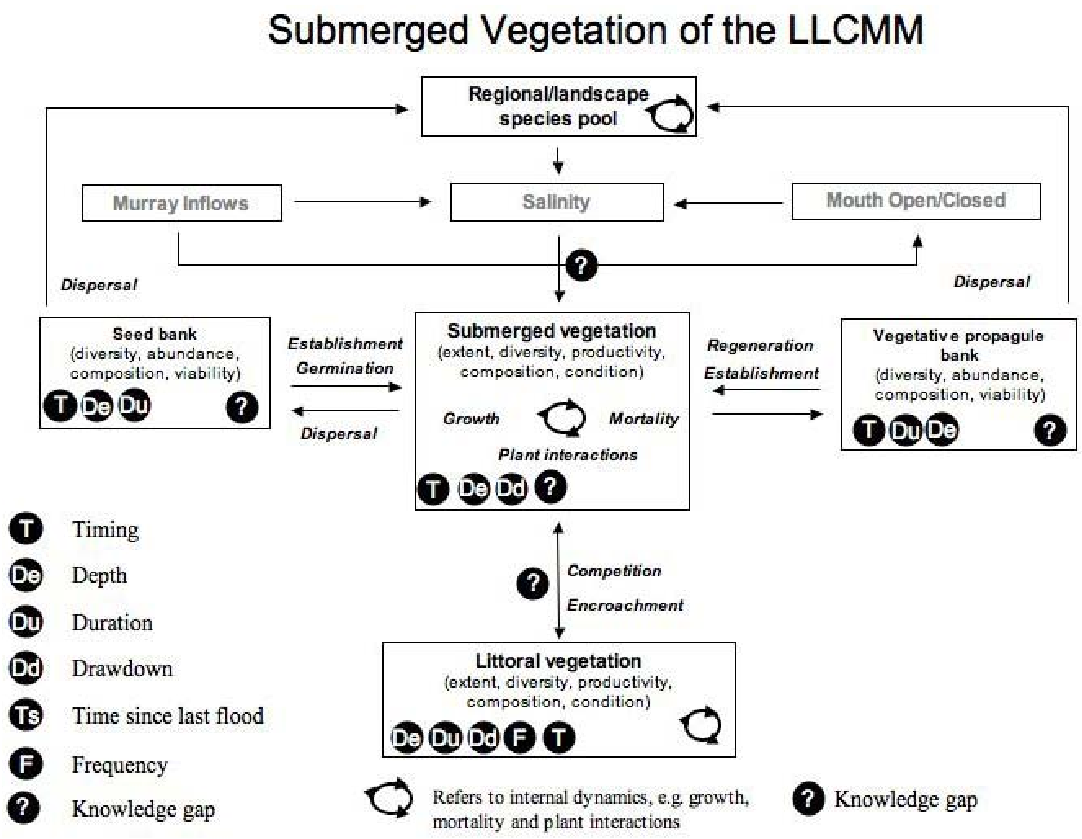

Figure 21: Conceptual model of effects of key flood attributes on vegetation dynamics of submerged vegetation communities of the Lower Lakes, Coorong and Murray Mouth (LLCMM) Icon Site

(N.B. dashed line indicates probable link).

Explanatory notes—submerged vegetation of the LLCMM conceptual model (Figure 21)

Extant vegetation: extent, character & condition

The submerged vegetation of the LLCMM is characterised by a diversity of marine, estuarine and freshwater species (Ganf, 2000). The distribution of these species is strongly dependent upon salinity, which in turn is dependent upon the extent of freshwater inflows from the River Murray and tidal penetration. Prior to barrage construction submerged communities would have consisted of marine, estuarine/brackish and freshwater floras but a substantial part of the estuary has been lost and therefore estuarine communities have been reduced in extent.

Prior to flow regulation much of the plant biodiversity would have been associated with floodplains and temporary wetlands, rather than with the main channel (Ganf, 2000). The submerged vegetation of the Lower Lakes is now restricted to inshore areas due to increased turbidity but may have been previously more widespread throughout the lakes (Ganf, 2000). *Ruppia* spp. (particularly *R. megacarpa* and *R. tuberosa*) are key submerged species in the LLCMM. *R. tuberosa* is widespread in the southern lagoon of the Coorong but has declined considerably in extent and quality (MDBC, 2006e). Continued population declines and depletion of seed and propagule banks will make recovery of *R. tuberosa* populations difficult without immediate remedial action (Paton, 2005).

Propagule banks: extent, character & condition

Many of the submerged species occurring in the LLCMM reproduce both sexually and asexually. The relative importance of each strategy varies between species and this may be reflected in the composition of propagule banks. There is little information on the propagule bank for this Icon Site but Paton (2005) has described the decline in the propagule bank of *R. tuberosa*. Future declines in the propagule bank will make successful re-establishment of *R. tuberosa* difficult even if environmental flows are enacted (Paton, 2005).

Vegetation regeneration

Water levels are important in the maintenance of submerged vegetation communities in the LLCMM. For example, *R. tuberosa* is a species of ephemeral mud flats and *R. megacarpa* is associated with permanent waters (Jacobs & Brock, 1982). *R. megacarpa* is intolerant of desiccation and is generally found in deeper water than *R. tuberosa* (Brock, 1982b). Depth distributions are also dependent upon light and increased turbidity in the LLCMM may influence the distribution of submerged vegetation and its capacity to regenerate following implementation of environmental flows.

Effects of neighbouring communities

Water levels in the Lower Lakes are less variable since construction and operation of the barrages. Stable water levels are potentially favourable for the growth of littoral emergent vegetation such as *Typha* and *Phragmites* that now form extensive stands in the Lower Lakes. With reductions in light availability through increased turbidity submerged vegetation will be competing with emergent littoral species for space in the littoral zone of the Lower Lakes (Ganf, 2002).

Knowledge gaps

Knowledge gaps identified by Lamontagne *et al.* (2004) and Paton (2005) are relevant to submerged vegetation in general. A better understanding of the water balance of the LLCMM Icon Site (e.g. better gauging of freshwater inflows, measurement of flows through the barrages, better modelling of lake water levels) is essential for producing realistic habitat models that can be used to develop management strategies for *R. tuberosa* and other submerged species (Lamontagne *et al.*, 2004). Paton (2005) emphasised the need for research on relationships between salinity, water levels and light availability so that maximum benefit can be obtained from environmental water allocations, when available. Little information is available about the population dynamics of other submerged species in the LLCMM.

7.5 Conceptual models for weeds

Three conceptual models examining relationships between flow and weeds are presented here (Figures 22–24). The first of these is at a community scale in a similar style to those models presented in Section 7.3 Figures 23 and 24 are species models, comparable to those presented in Section 7.2, for the significant and widespread weed species, lippia and sagittaria.

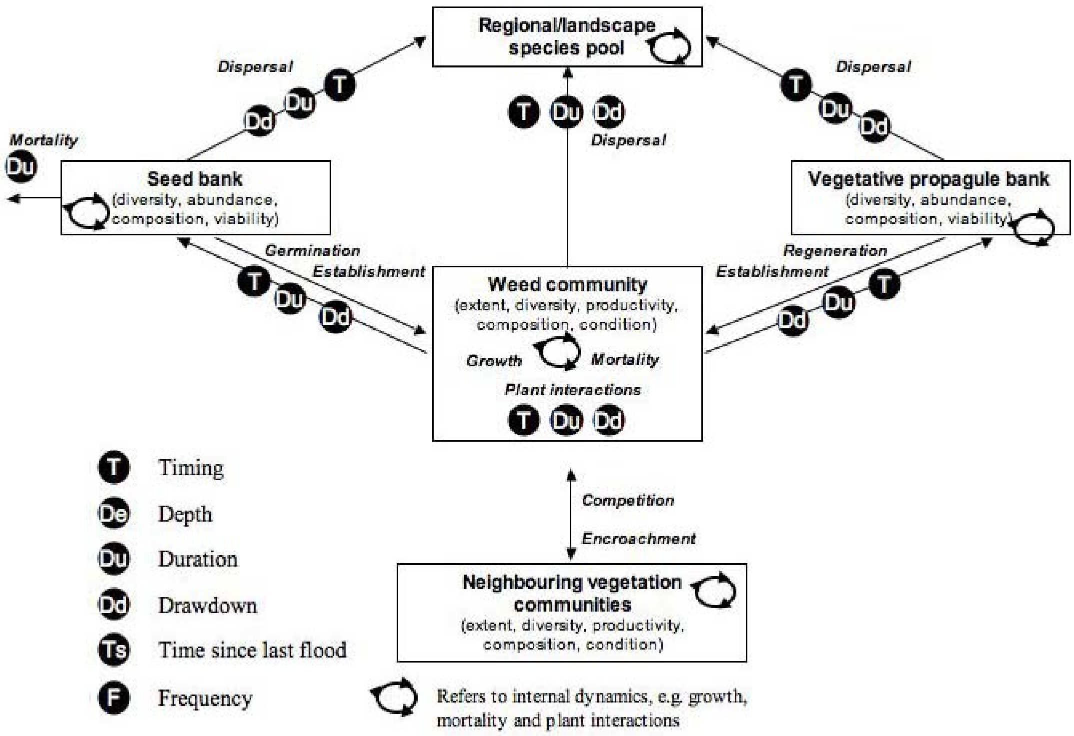

Figure 22: Conceptual model of effects of on weed vegetation of retaining water on floodplains

Explanatory notes—weed vegetation conceptual model (Figure 22)

Regional/landscape species pool

Retaining water on the floodplain is unlikely to directly influence propagule arrival to a specific icon site from outside although the increased duration of flooding may increase the opportunities for introductions via dispersal vectors other than water for example, wind, birds or animals. Alterations to hydrological habitat resulting from retaining water on the floodplain (flood duration, timing and draw down) may, however, influence the ability of plants to contribute to the regional species pool. Conditions (both abiotic and biotic) promoting weed growth and reproduction will replenish the propagule bank providing a source of propagules ready for dispersal.

Extant weed community: extent, character & condition

The primary influence of retaining water on the floodplain is increasing flood duration. This is likely to advantage the growth of species that are reliant on or, able to take advantage of, surface waters or water logged soils for at least part of their life cycle (i.e. submerged, floating and amphibious groups). Extended flood duration may also alter the seasonality of flooding. Floods may extend across a greater range of temperatures and increase the likelihood of weeds encountering their preferred temperature (and day length) ranges for germination and growth. This will depend upon the timing of floods. For example, floods that occur in winter but are retained into summer may provide opportunities for species better suited to warmer climatic conditions. The majority of the species reviewed here preferring surface waters or water logged soils (submerged, floating and amphibious groups) are perennials showing increased growth in response to higher summer temperatures. Some terrestrial species preferring damp conditions for germination (e.g. *Xanthium* spp.) may also be advantaged if, through extended flood duration, flood drawdown occurs in warmer months of the year.

The effects of retaining floodwaters on terrestrial weed will depend upon specific life history characteristics of the weed. Winter annuals, for example, tend to germinate in the autumn or winter and flower/set seed in late autumn, winter or early spring. Floods occurring during normal periods of vegetative growth (autumn, winter and spring) may cause mortality of extant vegetative growth and/or inhibit germination and growth of these species, prevent reproduction and hence replenishment of the seed bank. On the other hand, floods occurring outside their growth season are unlikely to impact directly upon terrestrial weed species unless the increased flood duration causes mortality to the seed bank if seeds are intolerant to moist conditions. Terrestrial weeds could, however, benefit from flood disturbances by taking advantage of dry conditions post-flooding when competing vegetation or litter have been removed.

Weed propagule banks: extent, character & condition

Weed seed banks reflect processes that replenish (seed production and dispersal) and deplete (germination, secondary dispersal and mortality) the propagule bank. Retaining water on the floodplain is likely to influence many of these processes. Increased flood duration may increase opportunities for germination of weeds able to germinate whilst submerged such as many wetland plants. For species with flood intolerant seeds, however, increased duration may cause significant mortality of seeds. Increase in duration may also alter the seasonality of flows providing increased opportunities for contributions to the seed bank from species able to grow in flooded conditions such as floating and amphibious species. Rates of drawdown are also likely to be affected by retaining water on the floodplain. Waters retained until warmer seasons will drawdown more rapidly due to higher evaporative losses than water retained until cooler winter months. This is likely to be important for amphibious and terrestrial weeds. Slow drawdown will provide opportunities for recruitment of species that prefer waterlogged or damp conditions allowing seeds to germinate before sediments dry out. Rapid drawdown, on the other hand, may promote the recruitment of exotic terrestrial species intolerant of waterlogged conditions.

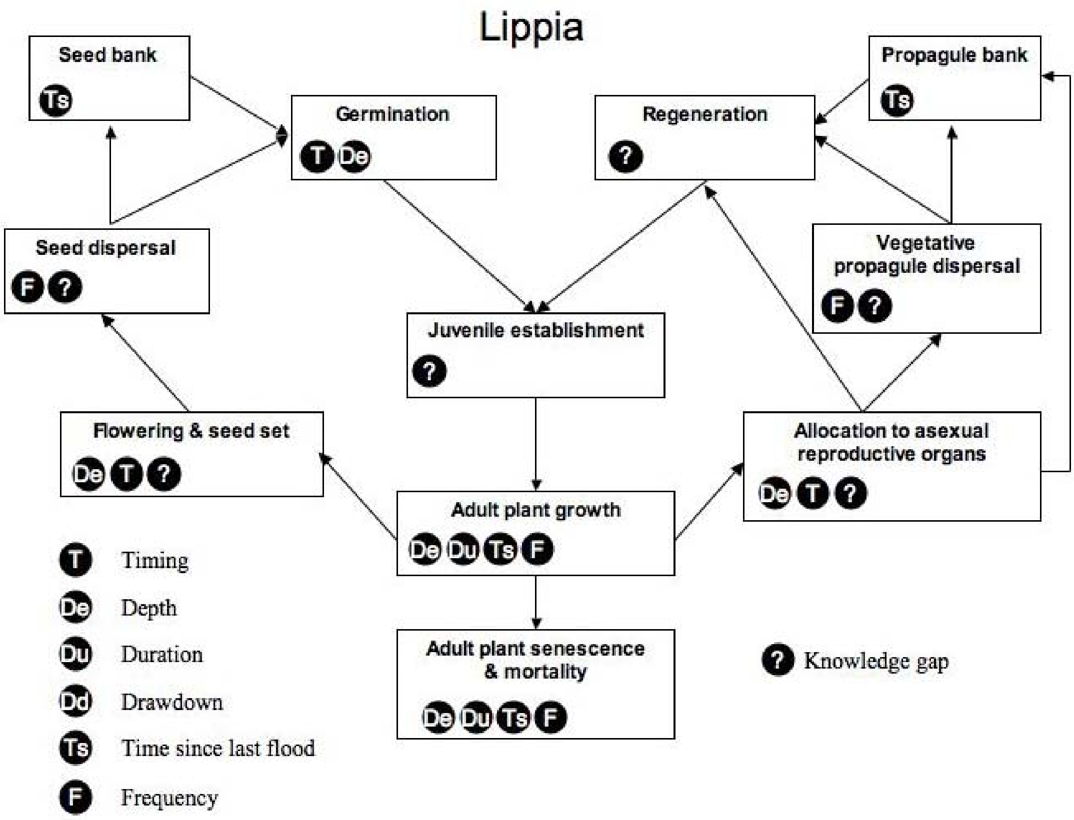

Figure 23: Conceptual model of effects of key flood attributes on major life history processes of lippia (*Phyla canescens*)

Explanatory notes—lippia conceptual model (Figure 23)

Plant growth, senescence & mortality

Growth and spread of *Phyla canescens* (lippia) is reported to be closely linked to flood duration and depth (Lawrence & Stokes, 2008). Lippia is able to survive inundation for 2–3 months each year in water depths in excess of one metre (Earl, 2003), although Taylor and Ganf (2005) found that growth of lippia stalled during inundation. The work of Blanch *et al.* (1999) also suggests that lippia is unlikely to survive flooding of more than 164 days in a two year period (or between 20–25% of the time) which corresponds with the observations of Earl (2003) and seems to require continuous exposure of at least 283 days in a two year period. In addition, McCosker (1994 cited in Mawhinney, 2003) reported that lippia is able to survive long durations submerged at less than 0.2m but following continuous submergence at water depths of 0.2–0.3m was replaced by native wetland plant species. Blanch *et al.* (1999) did not record lippia in areas flooded in water depths of 2m or more on the lower Murray floodplain. Reduced flood frequency is also believed to have favoured the spread of lippia (Price *et al.*, 2008).

Lippia has a deep tap root and is relatively drought tolerant (Lucy *et al.*, 2005 cited in Taylor & Ganf, 2005). Taylor and Ganf (2005) however, found the growth of lippia to be suppressed under the driest experimental conditions they imposed relative to the native grass, *Sporobolus mitchellii*. As the development of a deep tap root is likely to be key to lippia's capacity to survive drought, rate of drawdown relative to rate of tap root extension is likely to be critical. A rapid rate of draw down could out pace the establishment of the tap root compromising this species ability to survive drought.

Vegetative reproduction

Taylor and Ganf (2005) report the promotion of asexual reproduction in lippia during experimental spring top-flooding. When inundated morphological changes occur with internode thickening and stems become fragile and easily fragmented (Taylor & Ganf, 2005). These stem fragments may lay dormant for up to three months (Dellows, 2001). Dispersal of lippia is thought to be related to flooding (Earl, 2003).

Sexual reproduction

Lippia flowers in spring, summer or autumn in response to flooding or local rainfall (Lucy *et al.*, 1995 cited in Leigh & Walton, 2004). Taylor and Ganf (2005) report prolific flowering of exposed shoots suggesting that water depth will be important for flowering and seed production—a common requirement for many wetland plants (Cronk & Fennessy, 2001). Lippia seeds may also require flooding for germination (NLWG, 2009) and germination temperature preferences would suggest this species' establishment is promoted by flooding during warmer months when temperatures exceed 15°C (NLWG, 2009). Observations of McCosker (1994 cited in Leigh and Walton, 2004) suggest that germination may be enhanced by drying and wetting. Seeds of lippia are dispersed via floodwaters (Leigh & Walton, 2004). Unpublished research conducted at the University of New England and reported in the Lippia Management Manual (NLWG, 2009) suggests seed longevity possibly in excess of 10 years.

Knowledge gaps

- effects of flow on seedling establishment
- effects of flow on vegetative propagule regeneration
- factors influencing propagule dispersal.

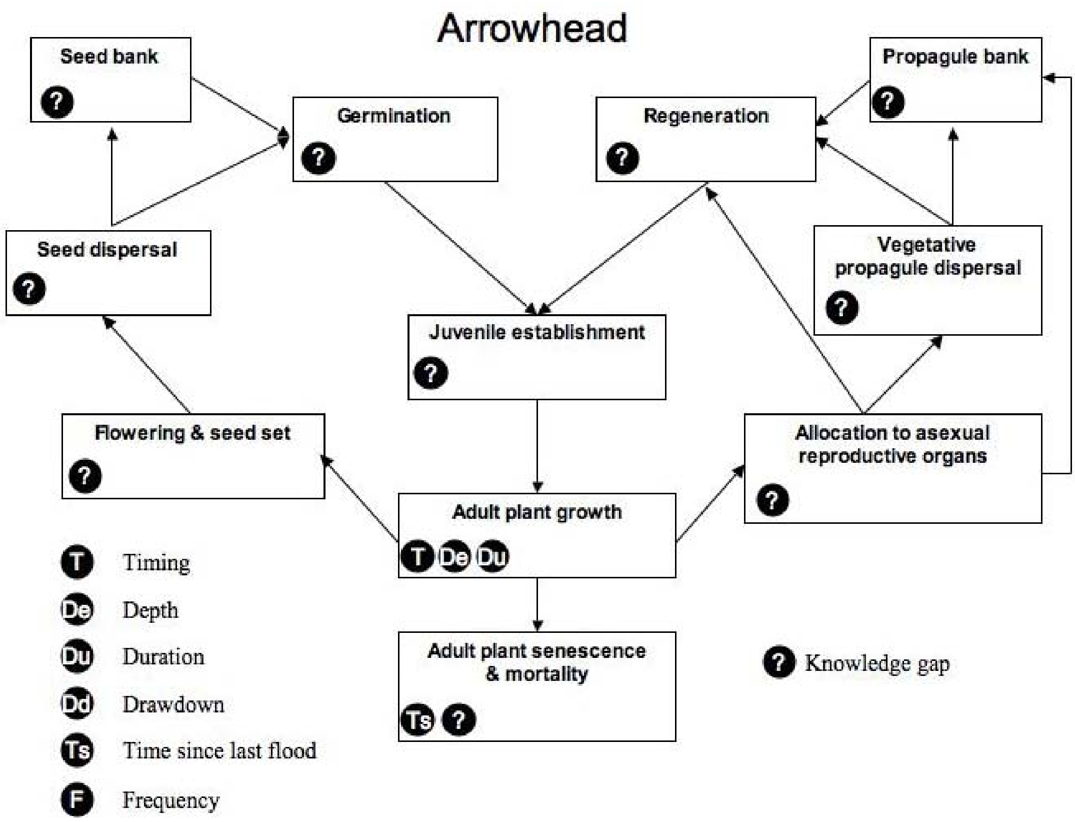

Figure 24: Conceptual model of effects of key flood attributes on major life history processes of arrowhead (*Sagittaria platyphylla*)

Explanatory notes—arrowhead conceptual model (Figure 24)

Plant growth, senescence & mortality

Sagittaria platyphylla (arrowhead) is reported to prefer relatively constant water levels in slow flowing areas within the water depth range 0—30 cm and is intolerant of deep waters (Maxwell, 2008). This depth range concurs with that of 30 cm reported by Martin and Shaffer (2005). According to Martin and Shaffer (2005), however, *Sagittaria* spp. species are often able to survive dramatic fluctuations in water level. This species appears to be relatively drought intolerant with a substantial reduction in infestations following drought in the Barmah and Millewa Forests wetlands (Maxwell, 2008). Summer flooding appears to be advantageous to this species (Maxwell 2008).

Vegetative reproduction

Arrowhead reproduces vegetatively by rhizomes and tubers which remain dormant during winter (Parsons & Cuthbertson, 2001). Spread is thought to be mainly through vegetative reproduction (Parsons & Cuthbertson, 2001).

Sexual reproduction

Arrowhead seeds germinate in spring and produce flowers from January continuing until late autumn (Parsons & Cuthbertson, 2001). Disturbance by livestock and European carp and herbivory by a variety of fauna are thought to aid the spread of both seed and vegetative propagules (Maxwell, 2008).

Knowledge gaps

- effects of flow on allocation to asexual or sexual reproduction
- effects of flow on vegetative propagule dispersal and regeneration
- occurrence of vegetative propagule banks and factors influencing their distribution, abundance, viability and regeneration from these
- factors influencing the distribution, abundance and viability of soil seed banks and seed dispersal
- effects of flow on seed germination.

8. Identification and prioritisation of knowledge gaps

8.1 Summary

There are considerable knowledge gaps concerning the effects of flow on floodplain understorey and aquatic vegetation in The Living Murray icon sites at both the species and community levels. At the species level, there appears to be a particular dearth of knowledge regarding relationships between flow and processes of recruitment, i.e. dispersal, germination, establishment and vegetative reproduction, for the majority of key species. Whilst there is some confidence in identifying which flow attributes are likely to affect the outcome of various life history stages, including both regenerative processes and adult plant growth, of key taxa and various functional groups, quantifiable thresholds are available for a very limited number of species. Table 8 provides a summary of major knowledge gaps concerning the effects of flow on various life history stages of the selected taxa examined in Section 7.

At the community level, major knowledge gaps associated with mechanisms of vegetation regeneration, including propagule dispersal and propagule banks, and the effects of flow on the contribution of these to vegetation dynamics pertain to all of the icon sites. Additionally, the level of natural variability in floodplain understorey and aquatic vegetation appears to be poorly described in most key communities at these sites. Plant-plant interactions, i.e. competition and facilitation, also represent a major knowledge gap in the icon sites, despite the potential importance of these for determining spatial boundaries between community types and therefore affecting vegetation diversity at a landscape scale. A summary of major knowledge gaps pertaining to the effects of flow on the vegetation dynamics of key floodplain understorey and aquatic plant communities in The Living Murray icon sites is provided in Table 9.

Table 8: Summary of knowledge gaps concerning the effects of key flood attributes on major life history processes of selected floodplain understorey and aquatic plants of The Living Murray icon sites

Knowledge gaps are indicated by question marks. A ✓ indicates reasonable knowledge of a process and ~ indicates the availability of some knowledge but warranting further research. A × indicates that available knowledge suggests this process (or the effects flow upon this process) is not relevant. Refer to Figures 2—11 for further detail.

Knowledge Gaps	common reed	cumbungi	giant rush	lignum	milfoil	Moira grass	rat's tail couch	ribbonweed	tuberous tassel	large fruit tassel
Occurrence of soil seed bank	?	✓	?	×	✓	✓	?	✓	?	✓
Occurrence of vegetative propagule bank	✓	?	?	~	?	?	?	?	✓	✓
Occurrence of vegetative propagule dispersal	?	?	?	?	✓	✓	?	~	?	✓
Effects of flow on plant growth, senescence & mortality	✓	✓	~	~	?	✓	~	~	~	~
Effects of flow on flowering & seed-set	?	?	?	~ (probably not relevant)	?	~	?	~	?	?
Effects of flow on seed dispersal	?	?	?	~	?	?	?	?	?	?
Effects of flow on soil seed banks	?	?	?	×	?	?	?	?	?	?
Effects of flow on seed germination	✓	✓	?	~	?	?	?	~	✓	~ (probably not relevant)
Effects of flow on allocation to asexual reproduction	?	?	?	?	?	~	?	?	?	✓
Effects of flow on vegetative propagule dispersal	?	?	?	?	?	?	?	?	?	~
Effects of flow on vegetative propagule banks	?	?	?	?	?	?	?	?	~	?
Effects of flow on plant regeneration from vegetative propagules	~	?	?	~	?	?	?	?	✓	?
Effects of flow on establishment	✓	~	?	~	?	?	?	~	~	~

Table 9: Summary of knowledge gaps concerning the effects of key flood attributes on vegetation dynamics of selected floodplain understorey and aquatic plant communities of The Living Murray icon sites
Knowledge gaps are indicated by question marks. A ✓ indicates reasonable knowledge of a process and ~ indicates the availability of some knowledge but warranting further research. Refer to Figures 13—21 for further detail.

Knowledge Gaps	ephemeral herb lands	reed-beds	giant rushlands	Moira grass plains	Lignum shrublands	river red gum woodlands/ forests	black box woodlands	weir pools	submerged vegetation of LLCMM
Effects of flow on community extent	~	~	~	✓	~	~	~	~	~
Temporal and spatial variability in extant vegetation composition and structure	~	~	~	~	~	~	~	~	~
Effects of flow on productivity and species extirpations (e.g. from local mortality)	~	~	~	~	~	~	~	~	~
Character & condition of seed banks	~ preliminary study on Hattah	~ inferred from other studies	?	?	~ inferred from other studies	~ inferred from other studies	~ inferred from other studies	?	~
Effects of flow on seed bank character & condition	~ preliminary study on Hattah	?	?	?	?	?	?	?	?
Effects of flow on contribution of seed banks to vegetation regeneration	~ preliminary study on Hattah	?	?	?	?	?	?	?	?
Character & condition of vegetative propagule banks	?	?	?	?	?	?	?	?	?
Effects of flow on vegetative propagule bank character & condition	?	?	?	?	?	?	?	?	?
Effects of flow on contribution of vegetative propagule banks to vegetation regeneration	?	?	?	?	?	?	?	?	?
Spatial and temporal patterns in propagule dispersal	?	?	?	?	?	?	?	?	?
Effects of flow on propagule dispersal	?	?	?	?	?	?	?	?	?
Role of plant-plant interactions	?	?	~ some knowledge for Barmah	~ some knowledge for Barmah	~ preliminary evidence from other studies	?	?	?	~
Effects of flow on plant-plant interactions	?	?	~ some knowledge for Barmah	~ some knowledge for Barmah	~ preliminary evidence from other studies	?	?	?	~

8.2 Knowledge gaps concerning weeds

A large number of exotic species are recorded within the Lower River Murray icon sites. Whilst risk assessments have been performed across the whole of the Murray–Darling Basin (Clunie *et al.,* 2006) and at individual sites (Chowilla floodplain; Nicol, 2007) it is unclear which weed species represent clear threats to the integrity of the Lower Murray icon sites. Unless weed risk is determined in a more coordinated manner across all the icon sites (rather than at individual site by site basis), there is a risk that effective management of a particular weed or pest species at one site will be undermined by lack of control elsewhere and subsequent reintroduction.

Biological and ecological information on some species is lacking, particularly in relation to their ecology in Australian systems. For example we could find little published information regarding the ecology of either *Sagittaria platyphylla* or *Alisma lanceolatum* in Australia. Research on other species such as *Phyla canescens* (lippia) is underway or completed but little of this information is currently available in the peer reviewed literature (e.g. Macdonald, 2007).

Weed propagule bank dynamics are poorly understood. Little information could be found regarding propagule longevity and factors affecting propagule viability (e.g. flooding, predation) of weed species.

Weed propagule dispersal is poorly studied and there is little information regarding the importance of hydrochory for dispersal, its importance relative to different propagule types and different flow regimes.

Little information was found regarding germination requirements of key weed species particularly in relation to moisture conditions.

Little information was found regarding the flood tolerance of seedlings of amphibious weeds. Seedlings are the growth stage most likely to be susceptible to disturbances such as flooding and hence knowledge of their flood tolerances could be used in the development effective management plans for these species.

8.3 Specific knowledge gaps for the Lower Lakes, Coorong and Murray Mouth

Lamontagne *et al.* (2004) have identified knowledge gaps for the Lower Lakes, Coorong and Murray Mouth. These knowledge gaps address how the physical and chemical environment would change during flow regime manipulations and biotic responses to changes in the physical and chemical environment. Many of the knowledge gaps identified are directly or indirectly related to aquatic vegetation (see Table 10). Arguably the most significant knowledge gap for this Icon Site is the response of aquatic vegetation to barrage removal and re-establishment of the salinity gradient. Ganf (2000) suggested that barrage removal would not guarantee the establishment of a flora resembling the pre-barrage flora, which reflects the range of issues that are currently influencing the distribution and abundance of aquatic vegetation in the LLCMM.

A significant knowledge gap relevant to the delivery of future environmental flows for LLCMM relates to the hydrology of the system. A barrage release in 2003 (MDBC, 2005b) showed that the hydrology of the LLCMM was poorly understood, as shown by the failure to accurately forecast flood travel in the lower Murray, an inability to gauge discharge through the barrages and an inability to accurately forecast lake levels (including the influence of reverse head i.e. movement of water upstream through the barrages caused by winds and tides) (MDBC, 2005b).

Table 10: Summary of specific knowledge gaps for Lower Lakes, Coorong and Murray Mouth (Source: Table 2 of Lamontagne *et al.*, 2004)

Management Lever	Knowledge Gap
Barrage Operation	• Response of water levels in the Northern and Southern Lagoons to barrage operation. • Verifying the relationship between barrage flows and mouth opening. • Mixing and transport of nutrients, sediments, salts and other contaminants along the Coorong by wind, tides, seasonal water level changes. • Nutrient budgets for the Coorong. • Spatial distributions of the primary producers, relative biomasses and turnover times, rates of primary production and linkages to bird and fish populations. • Sensitivity of nutrient regeneration processes to salinity. • Role of stratification in physical and biogeochemical dynamics in northern and southern lagoons. • Relationship between long term climatic variability and ecological status.
Delivery of Water from Upstream	• Sources and dynamics of turbidity in the Lower Lakes. • Light and water regime requirements for macrophytes. • Inundation model to assess impacts of water level regimes on macrophytes. • Factors determining occurrence of algal species in the Lower Lakes. • Hydrodynamic model (salinity and algal distributions). • Stratification in the Lower Lakes during calm periods. • Sources of carbon driving food chains in the Lower Lakes. • Habitat requirements for fishes. • Contribution of groundwater seepage to salinity in the Lower Lakes. • Improved water balance of Murray River and Lower Lakes. • Paleolimnological reconstruction of past environments of the Lower Lakes and Coorong.
Delivery of water from Morella Basin	• Sources and dynamics of turbidity in the Lower Lakes. • Light and water regime requirements for macrophytes. • Inundation model to assess impacts of water level regimes on macrophytes. • Factors determining occurrence of algal species in the Lower Lakes. • Hydrodynamic model (salinity and algal distributions). • Stratification in the Lower Lakes during calm periods. • Sources and dynamics of turbidity in the Lower Lakes.
Dredging	• Verification of the relationship between barrage flows and mouth opening and roles of wave action and littoral transport in sediment dynamics in and near the mouth.

9. Research priorities

9.1 Introduction

Tables 8 and 9 demonstrate the large number of current knowledge gaps that exist with respect to the effects of flooding on life histories of key floodplain understorey and aquatic taxa and vegetation dynamics of key communities of The Living Murray icon sites. Two key areas emerge from these tables:

i. Plant / community regeneration processes: i.e. mechanisms of dispersal, propagule banks, germination and establishment at the species level, amongst the majority of key taxa (including weeds), and at the community level, within the majority of key vegetation community types; and

ii. Plant-plant interactions: e.g. role of competition in maintaining spatial thresholds between community types and the effects of flow on this.

An additional area in which some limited information is available, but which warrants further research due to its significance and relevance to ecological management objectives, is the temporal and spatial variability in plant community composition, structure and character within key community types of the icon sites. This knowledge gap includes understanding variations in vegetation responses to floods of varying character. This is a key knowledge gap since in many cases Icon Site condition is currently inferred from the presence and abundance of certain floristic elements which may be highly variable even in relatively pristine, undisturbed floodplains, e.g. the presence or absence of flood-dependent taxa in the understorey of river red gum communities.

A further area which may require research attention in the future concerns potential synergistic effects of flooding and a range of extrinsic factors such as grazing, clearing, landscape factors etc.

Finally, there is a need for collaboration and consolidation of information pertaining to the classification of floodplain understorey and aquatic plants of The Living Murray icon sites into functional plant groups. Several schemes are currently employed depending on the Icon Site or monitoring program under question and, to the best of our knowledge; similarities and differences amongst these have not been investigated.

9.2 Research based on existing monitoring programs

Experimental designs employed by existing monitoring programs, both condition & intervention, appear to be quite thorough with respect to floodplain understorey and aquatic vegetation in all of The Living Murray icon sites with the possible exception of the River Murray Channel (although SRA reporting in 2011 may address this). We have not identified any major gaps or flaws in the design of existing data collection methodologies associated with ongoing monitoring programs although the collection of data concerning additional environmental variables, e.g. water quality, grazing intensity, landscape parameters etc., would be a valuable addition where these are not currently measured to enable future assessment of possible synergistic effects of extrinsic factors with flow.

Continued long-term monitoring similar to that already underway in the icon sites will enable gradual improvement in our understanding of how different key taxa and communities in each of the icon sites respond to flood events (and flow interventions) of varying timing, depth, duration, magnitude, drawdown and frequency. However, reaching this understanding will depend greatly on the approach taken to data analysis and assessment and the conceptual framework within which this is undertaken. Current assessment of understorey and aquatic vegetation condition in the majority of icon sites appears to rely heavily on trends-based assessment in which declines in desirable floristic elements, e.g. flood-dependent taxa, are interpreted as declines in condition. Since vegetation communities in these systems are highly variable, such a trends-based assessment may not be the best approach to condition monitoring. Alternatives may involve the development of models in which the character of certain indicators, e.g. the presence and abundance of particular plant functional groups, are predicted to change depending on antecedent conditions. With a greater understanding of the inherent variability in these communities, 'limits of acceptable change' (Phillips, 2006) could be set and revised with respect to ecological objectives and field data could be judged against these in order to assess condition.

In order to construct such models and work towards identifying 'limits of acceptable change', a greater understanding of the temporal variability in vegetation composition and structure must be achieved. In icon sites for which medium to long-term datasets are already available, this may be possible through further analyses of existing data (which have been beyond the scope of the current project). Consequently, we recommend a data trawling project that utilises existing data to describe the temporal and spatial variability in floodplain understorey and aquatic vegetation communities of icon sites with respect to hydrological conditions.

A corollary of the above recommendation, is that responses to flooding and drying of floodplain understorey and aquatic plants at the species level will also need to be assessed via analyses of existing datasets in order to determine community-scale variations. Classification of taxa into plant functional groups is likely to be a critical component of this process. Currently, numerous approaches to plant functional group classification are employed across the icon sites even though the majority of taxa are common amongst them. Consequently, we recommend that analyses of existing datasets from across all of the icon sites, where appropriate (i.e. possibly not in ruppia meadows), is conducted to develop transferable plant functional groups that will facilitate collaboration and data sharing between monitoring programs.

9.3 Immediate research priorities

Assessment of the condition of floodplain understorey and aquatic vegetation of the icon sites as well as the effects of flow interventions on this, requires an understanding not only of the inherent variability of these vegetation communities but also of their resilience or potential to respond to hydrological changes. In floodplain and aquatic vegetation, such resilience often relates to the capacity of vegetation to regenerate following disturbances such as flooding or drought. As processes of regeneration, at both the species and community level, have also been identified by this project as a major knowledge gap in our understanding of the effects of flow on floodplain understorey and aquatic plants and vegetation in the icon sites, the remainder of our recommendations for research focus on this area. Rather than recommending species level experiments which may be difficult to translate into processes at the scale of vegetation communities in the field, we recommend research at the community-scale that will also yield information about specific taxa. NB: Whilst no specific research priorities are identified for weed species, it should be noted that the proposed research areas have the potential to yield information on weeds as they do for other key taxa.

9.4 Future research priorities

Of the major knowledge gaps identified in this project, we have not made research recommendations concerning plant-plant interactions. Whilst we acknowledge that competitive and facilitative interactions are likely to be significant in these communities, we believe the priorities listed above to be more easily achieved in the short-term. We hope and encourage, however, researchers to investigate the complex role of plant-plant interactions in these systems in the future.

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