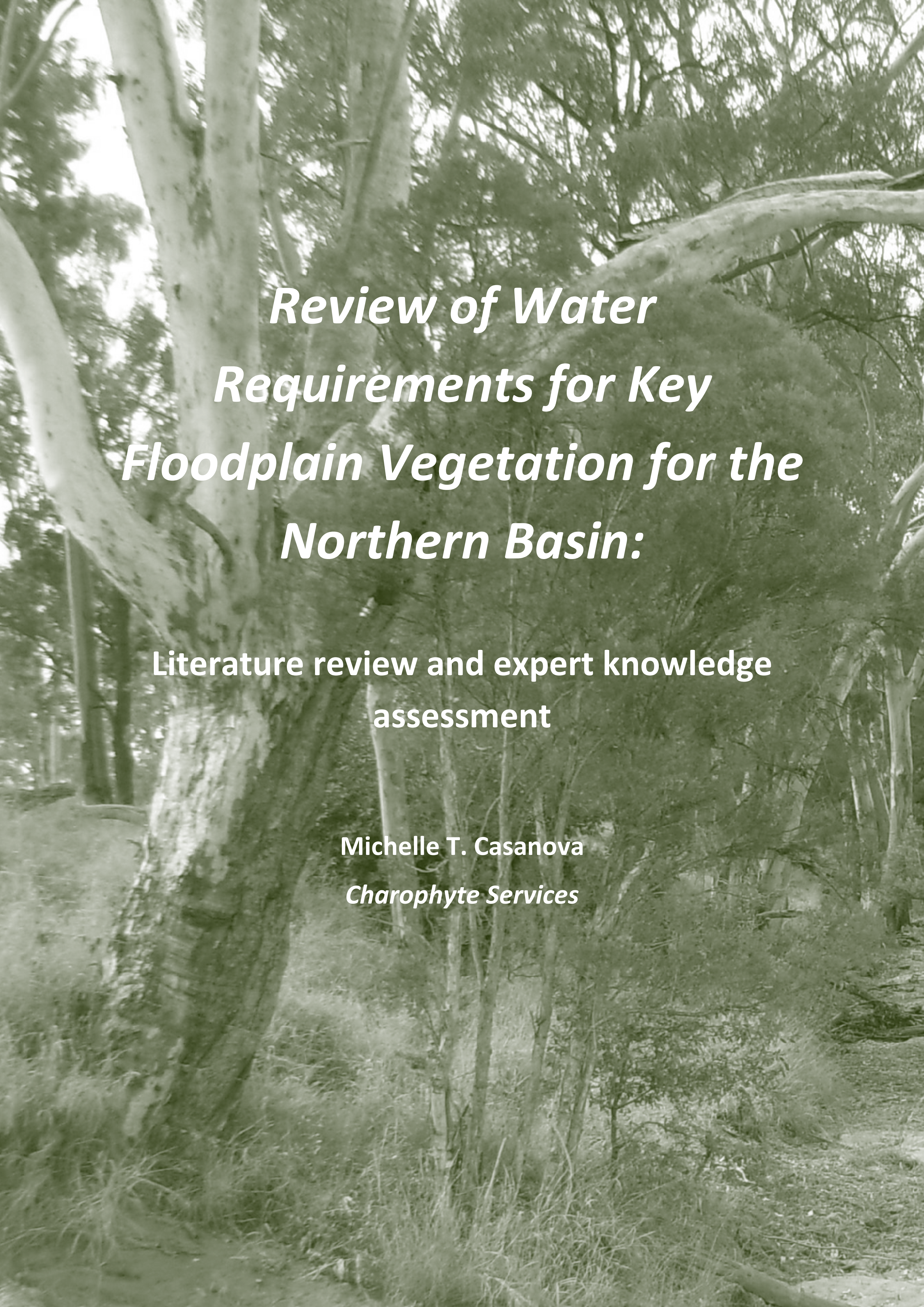

Review of Water Requirements for Key Floodplain Vegetation for the Northern Basin:

Literature review and expert knowledge assessment

Michelle T. Casanova

Charophyte Services

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The Murray–Darling Basin Authority acknowledges and pays respect to the Traditional Owners, and their Nations, of the Murray–Darling Basin, who have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. The MDBA understands the need for recognition of Traditional Owner knowledge and cultural values in natural resource management associated with the Basin.

The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of Darren Perry (Chair of the Murray Lower Darling Rivers Indigenous Nations) —

> *'the environment that Aboriginal people know as Country has not been allowed to have a voice in contemporary Australia. Aboriginal First Nations have been listening to Country for many thousands of years and can speak for Country so that others can know what Country needs. Through the Murray Lower Darling Rivers Indigenous Nations and the Northern Basin Aboriginal Nations the voice of Country can be heard by all'.*

This report may contain photographs or quotes by Aboriginal people who have passed away. The use of terms 'Aboriginal' and 'Indigenous' reflects usage in different communities within the Murray–Darling Basin.

EXECUTIVE SUMMARY

This *Review of Water Requirements for Key Floodplain Vegetation for the Northern Basin* was undertaken by botanist Dr Michelle Casanova as part of the Northern Basin Review. This report summarises the best available knowledge on the water requirements of key floodplain species, as at September 2015. The knowledge was obtained by:

- searching relevant databases to find all the available published and unpublished information to capture the latest and most relevant scientific knowledge to complement previous reports, particularly Roberts and Marston (2011 see table E1); and
- face to face and telephone interviews with experts, and a workshop with 18 botanical experts working across the Murray-Darling Basin so that the expert knowledge of scientists monitoring these species could be taken into account.

Draft findings were then reviewed by experts prior to the finalisation of the report.

Floodplain vegetation comprises species that require more water than falls on them as rain alone, but for which permanent inundation is lethal. The distribution of water in the landscape and the way that water is delivered in riparian zones, influences plant survival and reproduction, and ultimately their position in the landscape. Times of drought and flooding influence life-history events (e.g. reproduction, growth) and condition in these species. Different life-history events require specific amounts of water or components of the flow regime. A species 'water requirements' refers to the quantity, quality and timing of water needed to complete its life history. For riparian and floodplain species this is largely provided by flow along the river and associated riparian-zone ground water. Collectively the **depth**, **duration**, **frequency** and **timing** of water delivery (or availability, from all sources) in riparian and wetland systems is described by the term 'water regime'.

The review focuses on five floodplain plant species – River Red gum (*Eucalyptus camaldulensis*), Black Box (*Eucalyptus largiflorens*), Coolibah (*Eucalyptus coolabah*), River Cooba (*Acacia stenophylla*) and Lignum (*Duma florulenta*). These are all important species on the floodplains of rivers in the Murray-Darling Basin. However, these five are only a few of the species that occur in that habitat. Other tree, herbaceous, grassy, and shrubby species make up the vegetation that occurs on floodplains and in riparian zones. These other species also require water and respond to flow. Understanding how the key plant species use water at different stages of their life cycles, and how this changes in relation to tree condition can help inform strategies for delivery of the water regime that is needed to sustain those species (i.e. how often, how much, for how long, and when). Providing water for the key species can also provide water for the rest of the vegetation, particularly if plant species can be categorised into groups with specific water regime requirements. Provision of water for plants can provide water for the whole ecosystem.

This review contains detailed information about the water requirements of the five species. Some species like River Red gum and Black box are well-studied, so we understand their life history constraints, condition thresholds and the water requirements of populations. For the other species (Coolibah, River Cooba and Lignum) there have been fewer published studies, so the interview and workshop process was important for discovering information for those species. To the extent that it is available, science from the northern Murray-Darling Basin has been incorporated into this review. Appropriately, this knowledge has been complemented with studies from the southern part of the Murray-Darling Basin where gaps in knowledge existed.

Table E 1. Water regime requirements for the five key species summarised from Roberts and Marston (2011). The term *natural paradigm* refers to the unmodified, pre-European water regime. This table represents the best available knowledge in 2011, and should be referred to with reference to the original source document (Roberts and Marston 2011).

Species	Water regime requirements
River Red Gum	**For vigorous growth**
	Flooding about every one to three years for forests, about every two to four years for woodlands, depth not critical, duration about five to seven months for forests, about two to four months for woodlands, variability is encouraged, timing best in spring-summer
	For regeneration
	Flood recession in spring or later, follow-up flood for establishment, depth 20-30 cm, duration four to six weeks, but longer is tolerated
	Critical interval
	Flooding after about three years for forests, five to seven years for woodlands to retain vigour, longer intervals lead to loss in condition
Black Box	**For vigorous growth**
	Frequency every three to seven years, depth not critical, duration three to six months, timing probably not important (natural paradigm should be followed if possible)
	For regeneration
	Following flood recession on in run-in areas after rainfall, timing in spring-summer, additional moisture in first or second year likely to be beneficial
	Critical interval
	Trees may survive 12 to 16 years, but in poor condition with diminished capacity to recover
Coolibah	**For vigorous growth**
	About every 10 to 20 years, but could be as little as seven years, depth not critical, duration not known, timing not expected to be important
	For regeneration
	Likely to be on flood recession or in run-off areas after rainfall, timing not critical, additional moisture in the first summer likely to improve establishment
	Critical interval
	Not known, possibly 10 to 20 years
River Cooba	**For vigorous growth**
	Flooding about every three to seven years, depth not critical, duration about two to three months, timing not important
	For regeneration
	Conditions not known
	Critical interval
	Not known
Tangled Lignum	**For vigorous growth**
	Frequency about every one to three years for vigorous growth, three to five years to sustain, seven to ten years for persistence, depth not critical (< 1m), duration three to seven months (not continuous), timing not critical (natural paradigm should be followed if possible).
	For regeneration
	Duration not known, depth not critical, timing in autumn-winter, follow-up flooding nine to 12 months after germination likely to assist establishment. Flooding once every 12 to 18 months during first three years desirable, depth to 15 cm, duration four to six weeks, before or during summer.
	Critical interval
	Flood every five to seven years, although rootstock can survive up to 10 years,

The summarised outcomes of this review consist of life cycle diagrams and tables. Figure E1 and Table E2 (for River Red Gum *E. camaldulensis*) are given as examples of these results. Similar summaries of all the information collected for each of the species are provided in the body of the report. Some new information is available based on studies undertaken since 2011, especially in relation to the persistence of floodplain vegetation, some life history events, and specifically for Lignum. Little new information about how the Northern Basin vegetation water requirements differ from those of the Southern Basin vegetation was available. The main difference between the information provided by Roberts and Marston (2011) and the updated information in this review is the recognition of the influence of condition (referred to as *state* in the tables) on the water requirements of floodplain vegetation (after Overton *et al.* 2014). Floodplain vegetation can persist in declining condition for long periods of time when water is not provided. In general each species follows a decline pathway, progressing from *Good*, through *Medium, Poor* and *Critical* until *Death*. Restoration of the water regime required for vigorous growth (*sensu* Roberts and Marston 2011) for a single season does not generally restore the vegetation to a *Good* condition, if it has experienced severe decline (many years of water deficit). Some species are known to experience a different return pathway, via an *Intermediate* condition. Thus the number of years that water is not available impacts directly on the amount of water, and number of years of watering that must be provided to return the vegetation to good condition.

The floodplain vegetation water requirements in Roberts and Marston (2011) can be compared with the results of this review. Table E1 summarises Roberts and Marston (2011) for all the key floodplain species. The recommendations for *vigorous growth* in Table E1 coincide with the recommendations in this report for maintenance of River Red Gum (*E. camaldulensis*) in *Good* and *Medium* condition. The findings in this review coincide with all other recommendations for *E. camaldulensis.* The major knowledge gap for River Red Gum is whether the subspecies which occurs in the Northern Basin has the same water requirements. This report reveals a good knowledge base, and conceptual model, for recovery of River Red Gum from drought.

The recommendations for *vigorous growth* of Black Box (*E. largiflorens*) in Roberts and Marston (2011) (Table E1) have not been changed on the basis of this review, with the exception that trees might be able to persist longer without watering. The caveat that *they will be in poor condition with diminished capacity to recover* is still true, and probably more so after longer dry periods.

The recommendations for *vigorous growth* of Coolibah (*E. coolabah*) in Roberts and Marston (2011) has not been improved upon, with the exception of estimates of flood duration (9 days to 2 months). The critical interval between floods is still unknown, but there is more information about regeneration. A major knowledge gap concerns the difference between the two subspecies of Coolibah. They have different habitats and could well have different water requirements.

The recommendations for *vigorous growth* of River Cooba (*Acacia stenophylla*) in Roberts and Marston (2011) have been refined, so that trees in *Good* condition require flooding once every three years, and in *Medium* condition once every seven years. There have been some new results concerning regeneration, but these are mostly based on personal communications or reports in the grey literature. The critical interval between floods could be as long as seven years, but this is not based on empirical evidence.

The recommendations for *vigorous growth* of Lignum (*Duma florulenta*) in Roberts and Marston (2011) are confirmed by new data, however, the critical interval is likely to be longer than seven years. However (as Roberts and Marston (2011) note, the rootstock can be long-lived. There is more information about the regeneration of Lignum, and some of this is specific to the Northern Basin. It is also possible that the required season of flooding differs between the Northern and Southern Basins (spring in the south, summer in the north).

In summary, following the recommendations of Roberts and Marston (2011) for floodplain vegetation in the Northern Basin is likely to result in maintenance of the key species in the long-term. For the purposes of modelling, the frequency, timing and duration of flooding given in Roberts and Marston (2011) provide an adequate surrogate to describe the water requirements of the floodplain vegetation community (with the exception of submerged wetland and in-channel species). There is evidence that use of a single ‘Functional Groups’ approach throughout the Basin is likely to improve on this ‘key-species’ approach. This review did not reveal evidence that the recommendations are inappropriate for the Northern Basin. However, it should be noted that on-going studies (The Long Term Intervention Monitoring Program; The Living Murray; studies by staff of the Queensland Department of Science, Information Technology and Innovation and the Department of Natural Resource Management) could provide new, more targeted information.

The water regimes outlined here for restoration of *Good* condition are necessary for the maintenance and functioning of floodplain vegetation. However it is important to recognise that other factors can influence the successful restoration, recruitment or maintenance of vegetation. These include ground water depth and quality, and floodplain management including grazing. Ground water depth and quality impact on the maintenance of floodplain vegetation in the absence of above-ground flows, and floodplain management impacts on regeneration processes. To ensure the most efficient and effective use of environmental water, coordinated and targeted complementary actions need to be considered in an adaptive management framework that incorporates rigorous scientific monitoring and evaluation.

Table E 2. Water regime for the maintenance and decline in condition (*state*) of River Red Gum (*E. camaldulensis* subsp. *camaldulensis* (floodplain forest)). Further detail is provided in section 8 of this report.

State (*sensu* Overton *et al.* 2014)	Description	Flood frequency to maintain state	Dry period to cause decline	Flood frequency to cause recovery to *Good*
Good	Vigorous and healthy; canopy extensive, foliage density high, few dead branches, little to no epicormic growth	1 in 1–2 years, duration of 2–8 months	3 years to *Medium;* then 3 years to *Poor;* then 4 years to *Critical*	from *Intermediate*: 2+ in 5 years to return to *Good*
Medium	Not vigorous, canopy extensive, foliage density medium to sparse	1 in 2.5–3 years, duration of 2–8 months	3 years to *Poor;* then 4 years to *Critical*	from *Medium*: 1 year to return to *Good*
Poor	Not healthy, some branches dead, very sparse foliage or leafless	1 in 4–5 years, duration of 2–8 months	3 years from *Intermediate;* 4 years to *Critical;*	from *Poor*: 3+ in 9 years to return to *Intermediate,* followed by by 3+ in 5 years to return to *Good*
Critical	Leafless or with small tufts of epicormic growth, canopy dominated by dead branches and twigs	1 in 10 years, duration of 2–8 months	> 1 years to *Death*; time period dependent on cumulative stresses	from *Critical*: 5+ in 15 years to return to *Intermediate,* followed by 3+ in 5 years to return to *Good*

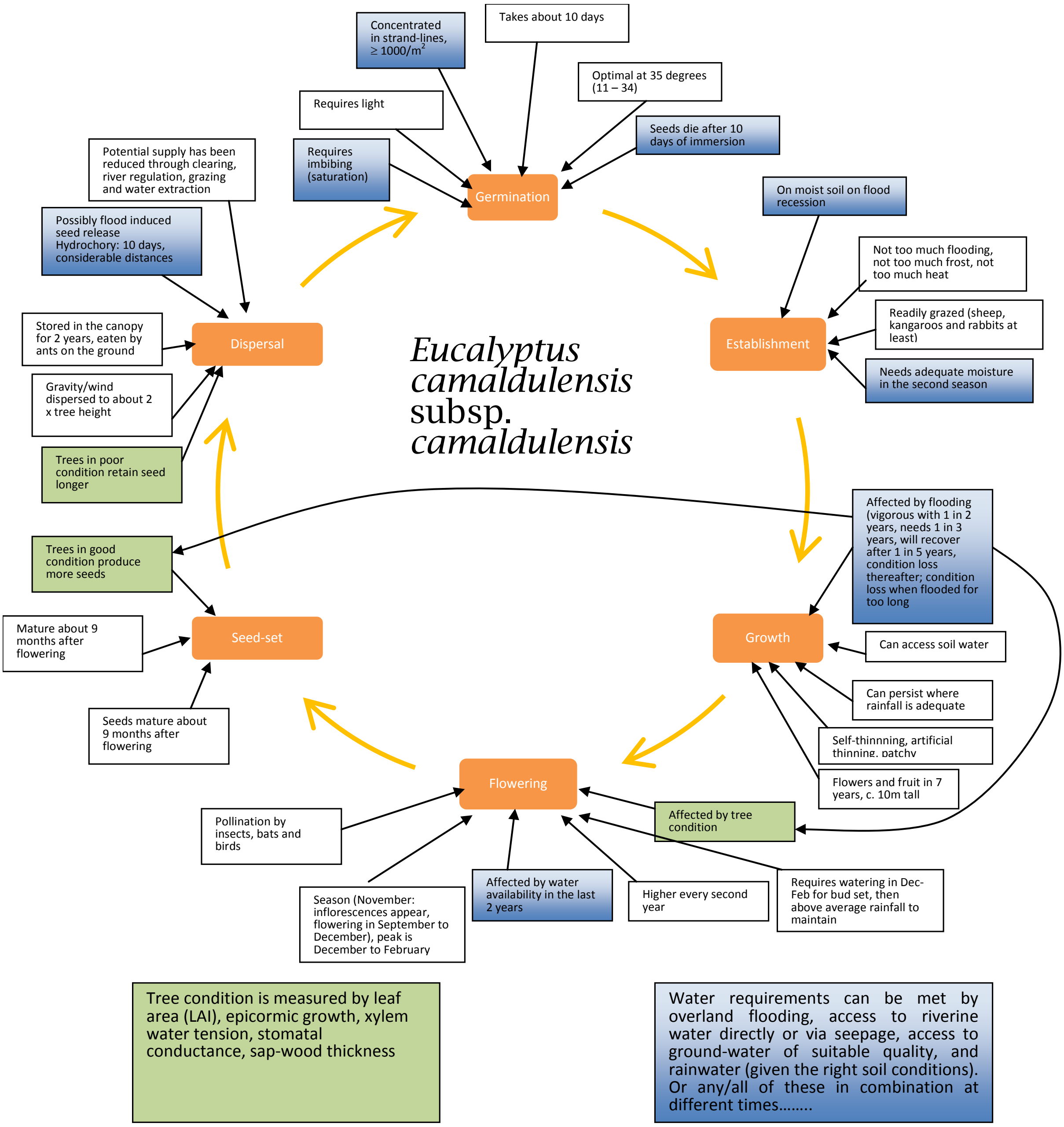

Figure E 1. Life-history diagram for River Red Gum *Eucalyptus camaldulensis* based on the information cited this review.

CONTENTS

1. INTRODUCTION

This review aims to summarise the latest knowledge concerning the water requirements of key floodplain vegetation species focussing on *Eucalyptus camaldulensis* (River Red Gum)*, E. largiflorens* (Black Box)*, E. coolabah* (Coolibah)*, Acacia stenophylla* (River Cooba) and *Duma florulenta* (Lignum), building on existing information, expert knowledge, published and unpublished research and other data, for input into the Northern Basin Review.

Floodplain vegetation comprises species that require more water than falls on them as rain, but for which permanent inundation is lethal. Both water deficiencies and water abundance restrict life history events and condition in these species, and different life history events require different components of the flow regime. The woody vegetation that is the subject of this review consists of a subset of the species that occur, and does not include all the tree species, or the herbaceous and grassy, or shrubby vegetation that also responds to and requires water in these systems. The five key vegetation species do not generally form a long-lived soil seed bank (Holland *et al.* 2013).

The key species have been chosen on the basis of their importance as indicators of water regime requirements for the broader vegetation community, as well as in recognition that their loss would have significant impact on the surrounding environment including river and soil properties. The species also have high value as habitat for birds and fish in the Murray-Darling Basin and their extent and condition can be monitored using remote sensing techniques. They are important constituents of riparian woodlands and forests, and flood-out or wetland areas. Woody vegetation can supply carbon via litter and debris to floodplain ecosystems (Baldwin 1999; Briggs and Maher 1983; Colloff and Baldwin 2010). These species are known to facilitate other biological processes by changing the abiotic environment. For example, tree species such as *Eucalyptus coolabah* can shade water (when it is present), lowering water temperature and affecting the retention of oxygen in the water. Roots in the water column provide shelter and habitat for fish (State of Queensland 2011).

Of the five species considered here, *Eucalyptus camaldulensis* has the highest requirement for water, and it grows closest to the river and channels. *Eucalyptus largiflorens* is more drought and salinity tolerant, usually located further from channels in elevated floodplain locations, whereas *Acacia stenophylla* occurs within *E. camaldulensis, E. largiflorens* and *D. florulenta* communities, as well as lining smaller channels (S. Capon personal communication), demonstrating both drought and salinity tolerance. Less is known about *E. coolabah*, despite its association with waterholes and riparian zones in literature. All tree species appear to be opportunistic water-users depending on soil type, recharge rates, aquifer conductivity, groundwater depth, groundwater salinity, flooding frequency and rainfall quantity. *Duma florulenta* is highly tolerant of drought, salinity and flood, and occupies intermittently flooded habitats throughout the Murray-Darling Basin.

Management of a species is predicated on the premise that a 'species'(or 'subspecies' in the case of *E. camaldulensis* subsp. *camaldulensis* and *E. coolabah* subsp. *coolabah*) is the same entity, and behaves in the same way, throughout the range of that species or subspecies. This is a reasonable assumption, as all individuals of a species are related to each other and have overwhelming genetic similarity, to the point where they can produce fertile offspring. However, some plants have less fidelity within a species than many animals, and hybridization with related species can occur where distributions of related species overlap. Similarly there can be gradual changes in species characteristics across their distribution, resulting in differences in tolerances and responses to environmental stimuli. For the purposes of this review we have assumed that each of the key species will exhibit the same basic life history, be constrained by the same limitations and respond in the same way to management activities throughout the range of that species or subspecies.

Water allocation planning for environmental needs should aim to provide flows that are as close as possible to 'natural', or to provide flow regimes that achieve specific environmental objectives while maintaining social and economic values (Acreman *et al.* 2014). Under the Murray Darling Basin Plan individual Water Resource Plans need to be compliant with the environmental flow objectives described in the Murray-Darling Basin Plan. The determination of environmental flow objectives can be enhanced by a well-informed, scientific knowledge of the water requirements of key species or key communities. Where sufficient information is available about the biotic responses to inundation (e.g. Driver *et al.* 2004; 2013; Casanova 2011), and the relationship between flow and inundation can be measured or modelled (Driver *et al.* 2005; Doody *et al.* 2009a; Chen *et al.* 2011; Chen *et al.* 2012) the ecological responses of floodplain species to flows can be inferred (e.g. Wen *et al.* 2013a; 2013b; Bino *et al.* 2015). A potential constraint is the knowledge about the demography, the drivers and thresholds for life history events in different species.

There is a significant relationship between the condition of floodplain vegetation, ecosystem function and the fauna communities supported by that vegetation (McGinness *et al.* submitted). Where floodplain water is supplied, it has 'whole system' consequences, with increased primary productivity, food web development and habitat provision (McGinness *et al.* submitted), as well as recruitment of understory species (Johns *et al.* 2010) and improvement of condition in trees (e.g. Llewelyn *et al.* 2014). Floodplains that support the species listed in this review also support species protected under international agreements such as the Ramsar Convention, Migratory Bird Agreements, and species listed as vulnerable, rare or endangered under Commonwealth and State legislation (MDBA 2012a). Thus supplying resources for the floodplain vegetation has 'flow-on' effects that achieve a number of ecological management objectives (MDBA 2012a).

The Murray-Darling Basin can be considered as two sub-catchments; the Northern Basin (comprising all rivers and catchments of the Darling River upstream of Menindee Lakes), and the Southern Basin (MDBA 2011). The Northern Basin has had a shorter history of water resource development than the Southern Basin, except in the eastern uplands, where clearing has occurred and agricultural and urban uses of water resources has been on-going for c. 120 years (Biggs *et al.* 2013). There was an expectation that if the current infrastructure for water extraction in the Northern Basin were used to its full potential (Cullen *et al.* 2003) then the area of floodplain vegetation would be reduced and trees replaced with grassland, impacting on the natural values of wetlands of national and international importance (e.g. Narran Lakes, Culgoa and Culgoa Floodplain National Parks). Most of the information on floodplain vegetation water requirements has been derived from studies in the Southern Basin (Roberts and Marston 2011; Rogers and Ralph 2011; Colloff *et al.* 2015), due to a paucity of information available for the Northern Basin (Hale *et al.* 2014). Roberts and Marston (2011) provided an 'optimal' water regime, targeted at maintenance, vigorous growth and recruitment of a number of floodplain species. The problem of paucity of knowledge about species in the Northern Basin is slowly being addressed, with more research and monitoring being undertaken into the floodplain vegetation of the northern Basin (e.g. MDBA 2012a; Kath 2012; Kath *et al.* 2014a; Kath *et al.* 2014b; Capon *et al.* 2012; Murray *et al.* 2012; Capon *et al.* 2015; Bino *et al.* 2015).

Floodplain ecosystems of the Murray-Darling Basin are naturally resilient to variable conditions (Colloff *et al.* 2010) and are adapted to episodic floods and droughts. The mechanisms of resilience, resistance and response in plant communities range from avoidance of drought, regeneration through vegetative means, reliance on a dormant seed bank or dispersal of seed (Eldridge and Lunt 2010), tolerance of hydrological extremes (Capon *et al.* 2009), to rapid responses to immediate hydrological conditions, or combinations of these. Resilience incorporates a flexible use of resources by floodplain vegetation. Recent research indicates that woody species might have greater flexibility in their capacity to tolerate drought than has been recognised in the past (Doody *et al.* 2015).

There is recognition that floodplain vegetation can access water from a variety of sources to fulfil some life-history requirements. The top layer of groundwater, the unconfined alluvial aquifers (e.g., palaeochannels in northern NSW; Vervoort and Annen 2006), are critical for the maintenance of the condition of deep-rooted plants, including trees, in the absence of surface water (Mensforth *et al.* 1994, Foster 2009; Cunningham *et al.* 2011). Rainfall can also be used for growth and maintenance (as occurs for *E. camaldulensis* in non-riparian areas), and can be a stimulus to germination (Jensen 2009). Although these sources of water can augment the water obtained from riparian flow, they (along with flow regimes) are subject to change. Deeper groundwater (≥ 30m deep) responds to catchment-wide conditions (MDBA 2012a), whereas shallow aquifers can respond rapidly to local surface water conditions (e.g. in the lower Lachlan River, Driver *et al.* 2004, 2011). Groundwater (whether shallow or deep) can be of variable quality (Silburn et al. 2013), and can be modified by changes in riparian flows, as well as agricultural extractions (e.g., Foster 2009 [Barwon-Darling], Driver *et al.* 2014). Rainfall is naturally extremely variable (particularly in the Northern Basin) and is predicted to decrease by 3–5 % in south-east Queensland under a changing climate (State of Queensland 2010). Projections of change to warmer temperatures, decreased winter rainfall, and increased variability for south-east Queensland have a high degree of confidence (www.climatechangeinaustralia.gov.au/). Floodplains, floodplain species and plant communities are highly vulnerable to climate change (Colloff et al. 2010; Capon et al. 2013; Fu et al. 2015), especially with interacting land and water-use impacts (Davis *et al.* 2015) . The expected changes (less total rainfall and a change in the distribution of rainfall: Jones et al. 2007), more episodic rainfall events (Alexander et al. 2007), higher evaporation rates, more frequent and more severe droughts, are likely to result in a reduction in inflows into the Basin (Adamson et al. 2009). This will impact floodplain processes (Neave et al. 2015) and hence needs to be considered in the implementation of the Murray Darling Basin Plan.

Floodplain species have evolved life history strategies in direct response to natural flow regimes (Bunn and Arthington 2002). The existence of distinct floodplain vegetation restricted to riparian systems indicates that the establishment and maintenance of that vegetation has been dependent on historical riparian processes; flow extent, duration and frequency, regardless of other sources of water: i.e. groundwater and local rainfall. The comprehensive synthesis and user-friendly summary of the best available information on floodplain vegetation water requirements provided by Roberts and Marston (2011) has been our best source of information on floodplain vegetation water requirements. Despite limited data on some species (Hale *et al.* 2014), the summary provided the best, up-to-date, specific recommendations about the season, duration and frequency of inundation required for all the species that are the subject of this review.

Recent investigations in the northern Murray-Darling Basin (Holloway *et al.* (2013) citing Marshall *et al.* (2011)) have identified the occurrence of floodplain vegetation in areas that have dry spells (i.e. no overbank flooding) that exceed the duration of drought that the vegetation is supposed to be able tolerate (and suggesting therefore the published tolerance thresholds described within Roberts and Marston (2011) appear less applicable to these northern locations. Holloway *et al.* (2013) suggested that there are data showing that established populations of these species might be using groundwater, particularly during periods of reduced surface-water availability.

The desk-top study by Marshall *et al.* (2011) (that provided some of the new data referred to by Holloway *et al.* 2013) suggested that current descriptions of floodplain vegetation water requirements were not accurate for the Queensland Murray-Darling Basin. The study consisted of a comparison of different buy-back volumes in the Murray-Darling Basin Plan with pre-development flows, and the predicted risk of exceeding thresholds of concern (ToC) for different ecological assets. The majority of information about the water requirements of the key floodplain vegetation used in this study was from Roberts and Marston (2011, and studies cited therein), and it was noted that there had been few studies of the floodplain vegetation water requirements in the Northern Basin (Marshall *et al.* 2011; Holloway *et al.* 2013; Reardon-Smith *et al.* undated). They identified the need for research to understand the vegetation-groundwater interactions, and the ecological role of large floods in the region.

The Northern Basin Science Review (Hale *et al.* 2014) identified knowledge gaps in relation to how floodplain vegetation in the Northern Basin (the Balonne, Culgoa, Condamine, Barwon and Darling Rivers) responds to flows, and how that response might be modified by, or interacts with, rainfall and groundwater. The review relied heavily on the knowledge provided in Roberts and Marston (2011), but stated that the relevance of that knowledge to the Northern Basin was uncertain (Hale *et al.* 2014). Scientific information regarding floodplain vegetation water requirements in the Northern Basin has been difficult to obtain (J. Roberts personal communication), largely as a consequence of the apparent paucity of studies. This review aims to determine if there is more, and more recent, information concerning the water requirements of floodplain vegetation throughout the Murray-Darling Basin that might address that issue.

1.1. SOURCES OF WATER IN FLOODPLAIN ECOSYSTEMS

Floodplain ecosystems are formed by their hydrology, in response to the underlying geology and soils. The vegetation communities that develop in relation to particular flow regimes are characteristic of each catchment and sub-catchment. A basic tenet is that floodplain vegetation is reliant on characteristics of the fluvial water regime to develop its particular character and carry out processes such as primary production and provision of habitat and resources.

Groundwater availability is dependent on geology and topography: models show that there is both discharge to riparian systems, and recharge from riparian systems, which impacts on riparian and groundwater salinity and the health of riparian vegetation (Middlemis 2010). Channel-full flows can influence groundwater (by local recharge from the channel to the bank) and overbank flooding can reduce groundwater salinity. This occurs through vertical infiltration from the surface and by upwards movement of low-salinity groundwater into the unsaturated zone (Holland *et al.* 2013). Floods have been found to do more, and be better, than artificial watering (Holland *et al.* 2013) due to their extent and duration compared to artificial events. Overbank flooding reduces the salinity of the soil above the water table, and also reduces the salinity of the upper levels of the groundwater (Holland *et al.* 2013). Additionally, studies that compare the effects of rainfall and flooding on soil processes have shown that flooding makes a substantial contribution to moisture in the soil profile in semi-arid zone floodplains (Baldwin *et al.* 2013).

A study by Holland *et al.* (2011) in South Australia, where the floodplain is characterised by highly saline soils and groundwater (essentially a unique hydrological environment), found that extraction of groundwater (by pumping for irrigation) can increase the local soil salinity (1–5 % each year), that vegetation within 50 m of the river uses 105–287 mm of groundwater in addition to rainfall, and that vegetation further from the river does not use detectable volumes of groundwater (Holland *et al.* 2011). They also found that the use of groundwater by riparian vegetation is limited by the salinity of that groundwater and that tree health can be improved by creating a long-term source of freshwater (Holland *et al.* 2011). The long-term consequences of reliance on groundwater by riparian vegetation can result in a local increase in soil-salinity, which needs to be removed periodically (by flooding or rainfall) to sustain the rate of groundwater use (Holland *et al.* 2011).

1.2. OTHER FACTORS THAT MIGHT INFLUENCE THESE SPECIES

There have been multiple historical stressors to floodplain vegetation in the Murray-Darling Basin, including clearing (Cox *et al.* 2001), forestry, grazing and gold mining (Mac Nally *et al.* 2011; Colloff *et al.* 2015). The historical impacts of European colonisation on both landscape utilisation and water resource development have been incremental and widespread (Gell and Reid 2014; Casanova 2015). Water resource and infrastructure development, including river regulation, is a more recent stressor on floodplain vegetation (Steinfeld and Kingsford 2013; Mac Nally *et al.* 2011; Colloff *et al.* 2015), and climate change will likely have an additive effect (Capon *et al.* 2013; Fu *et al.* 2015). Stresses can be additive or interactive, and act differently on different life history stages of trees (Niinemets 2010) and there are ongoing declines in the condition of riparian woodlands in the Northern Basin (Condamine River: Reardon-Smith *et al.* 2008). Regional issues that affect water availability to floodplain vegetation in the Murray-Darling Basin include localised water diversion and abstraction, aquifer draw-down in the underlying Great Artesian Basin and hydrological alterations associated with urban development and changing land-use (Davis *et al.* 2001). In the Northern Basin groundwater studies have been reviewed for the Condamine Basin, but knowledge of the pre-development characteristics, recharge and drainage are poor (Dafny and Silburn 2013).

Removal of trees (cutting for firewood, clearing paddock trees, clearing along fence lines, installation of fire breaks and road widening) can have significant effects on adult tree populations, depending on locality (Taylor *et al.* 2014). Development of tree hollows (which provide habitat values) can take hundreds of years, and removal of adult trees can impact on this (Taylor *et al.* 2014).

Exotic species are widespread throughout the Murray-Darling Basin. A review of species lists for wetlands in Australia revealed the most widespread species in wetlands are weeds (Casanova, Nielsen, Finlayson, Ward and Driver, unpublished). The impact of weeds is unquantified, but exotic tree species can compete with native vegetation. The exotic *Pinus halpensis* and willows (*Salix* spp.) use more water than native vegetation, and removal of these species results in a reduction in community evapotranspiration (Gehrig 2010; Swaffer and Holland 2014).

The condition of floodplain vegetation can be impacted by surrounding land-use (dryland or irrigated agriculture). For *E. largiflorens* there were no clear linear relationships between intensity of surrounding irrigated land use and vegetation condition and structure over all sites investigated along the Murrumbidgee River (McGinness *et al.* 2013). However, within the mid-Murrumbidgee, vegetation structure in *E. largiflorens* communities was simpler at sites surrounded by high intensity irrigation, compared to medium and low intensity irrigation (McGinness *et al.* 2013). Clearing to provide land for cropping and irrigated agriculture and infrastructure directly impacts the cover of native vegetation in the Macquarie Marshes and the Gingham-Gwydir wetlands including *E. largiflorens* and *E. coolabah* (Macquarie Marshes: Bowen and Simpson 2010a) and *A. stenophylla*, *E. coolabah* and *D. florulenta* (Gingham-Gwydir: Bowen and Simpson 2010b).

Grazing (both as a surrounding land use, and within floodplain plant communities) has a number of positive and negative effects on vegetation in general (Casanova 2006). Grazing removes biomass, introduces faecal material and weeds, moderates competition among plant species, and grazing animals alter the physical conditions of the floodplain. Studies show that grazing affects seed supply of tree species, as predation of seeds by ants occurs differently under different grazing regimes (Meeson *et al.* 2002). Grazing can affect the retention of litter in riparian zones, which, in turn, affects key species regeneration (Capon and Balcombe 2015). The positive effects of flooding on *E. camaldulensis* seedling growth can be negated by grazing, and to a lesser extent, soil salinity (Horner *et al.* Submitted). If we rely solely on the return of more natural flows we might still not see floodplain tree establishment because of the varied effects of grazing (Meeson *et al.* 2002).

Understanding the water requirements for key life history processes can inform models to predict changes in vegetation states, particularly if thresholds are identified (Bino *et al.* 2015). Models of *Eucalyptus* stand condition in The Living Murray Icon Sites have been developed, based on satellite imagery coupled with on-ground assessments (Cunningham *et al.* 2009a; Cunningham *et al.* 2010) culminating in the 2012 Stand Condition Tool (Cunningham *et al.* 2013).

Models based on time-periods for which there is good data (i.e. the last 20 years) could underestimate the flow conditions under which vegetation communities developed and have been sustained, if the last 20 years is not representative of the long-term patterns of inundation. Consideration should be given to preceding conditions and thresholds (Bino *et al.* 2015; Overton *et al.* 2014). Precedent conditions include not just the last year or two of flooding and rainfall, but conditions that existed throughout the life history of the extant vegetation. e.g. tree establishment can be assumed to have occurred in response to a sequence of favourable conditions of water availability (over a number of seasons), season of flooding and temperature range, as well as grazing pressure and land-use. Where landscape-scale models have been developed (e.g. Kath 2012; Kath *et al.* 2014) a combination of hydrological and landscape characteristics have been found to predict the presence of *E. camaldulensis*, and different size-classes of trees are related to different combinations of hydrological and landscape characteristics. Thresholds could be sequences of events (e.g. low rainfall years) that cause physiological stress from which a tree cannot recover, although it might take years for that consequence to be detected.

Roberts *et al.* (2009) provided a generalised, two-part model of factors that affect: 1) the regeneration and recruitment of trees and shrubs (Fig. 1a), and maintenance and/or persistence of floodplain trees and shrubs (Fig. 1b). This descriptive model partitions the landscape effects (clearing, salinity) from the hydrological effects (water availability linked to rainfall, flooding and groundwater) on the health, condition, growth and structure of the vegetation.

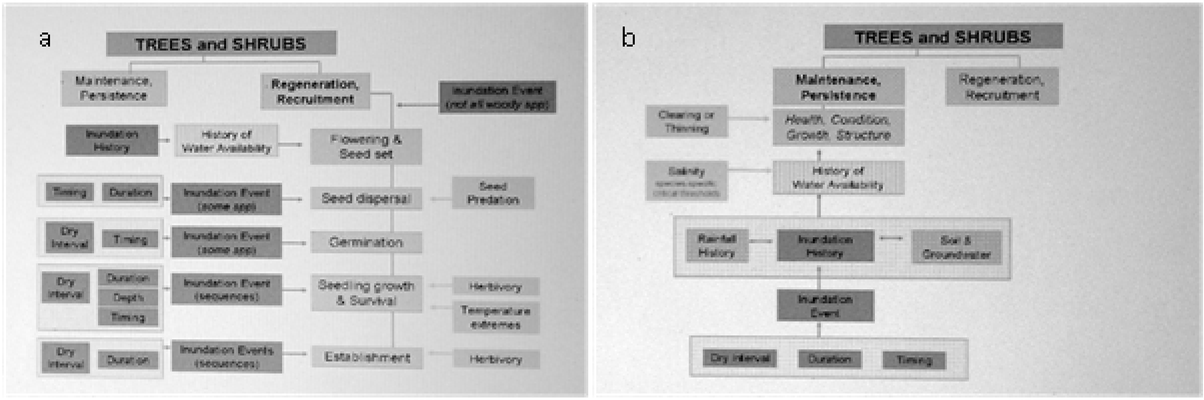

Figure 1. Model of factors affecting a) regeneration or recruitment and b) the maintenance and/or persistence of floodplain trees and shrubs (from Roberts *et al.* 2009).

Johns *et al.* (2009) produced a similar model, but separated more of the landscape effects, aspects of the life history affected by those, as well as hydrological regime (Fig. 2).

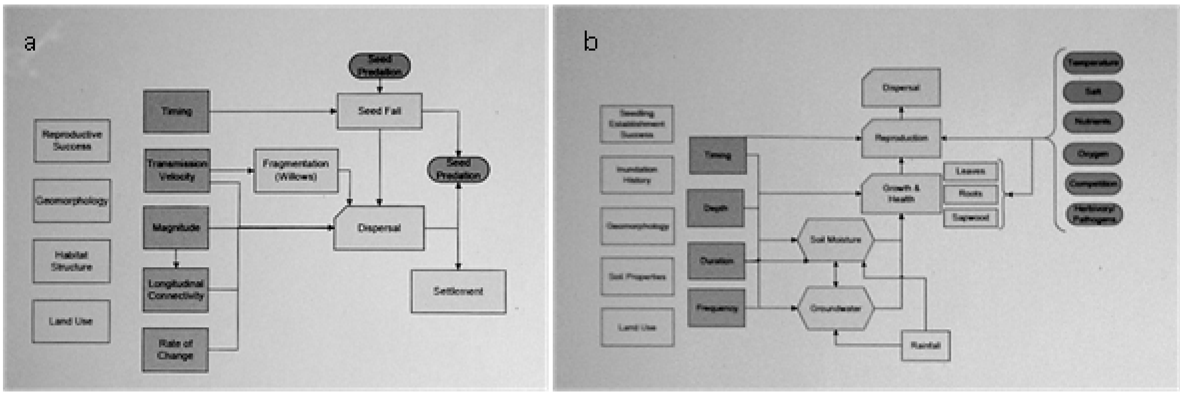

Figure 2. Model of factors separating landscape effects on life history process for a) maintenance and b) regeneration of floodplain vegetation (including Willows, *Salix* spp) (from Johns *et al.* 2009).

Mac Nally *et al.* (2011) focussed on only *E. camaldulensis* but provided a detailed model of the demography and those environmental factors that either promote or reduce the performance of *E. camaldulensis* during different stages of its life history. As models are improved for floodplain vegetation responses to water regime (and other confounding factors) our ability to predict requirements and responses improves (Fig. 3).

Colloff *et al.* (2015) provided a conceptual model of woody vegetation responses to flow, as well as an analysis of *E. camaldulensis* and *E. largiflorens* responses to environmental water in three localities. There is a good summary of knowledge in Johns *et al.* (2009).

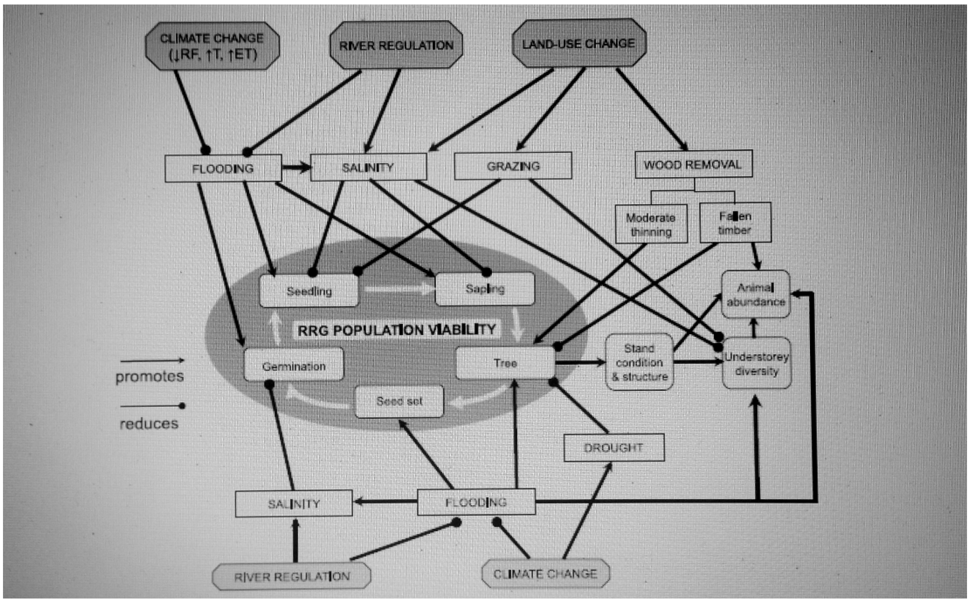

Figure 3. Model of *E. camaldulensis* life history in relation to the environmental factors that influence processes, along with the direction of influence (from Mac Nally *et al.* 2011).

A recent review of hydro-ecological knowledge of floodplain vegetation water requirements across the Southern Basin has been undertaken by CSIRO (Overton et al. 2014) (see Figure 10 in chapter 8). In this study a 'state and transition' model was used, with the condition of floodplain trees and shrubs (and other vegetation) categorised into defined 'states', and the transitions (due to 'stress' and 'recovery') between these states defined through the use of preference curves and rules. State and transition models were developed for six flood dependent vegetation 'Ecological Elements' with varying water requirements. Two of the most significant characteristics of the models developed are the incorporation of hysteresis (i.e. the time and addition of resources required for recovery from stress are not equal to the time and resource removal that induces the stress), and the incorporation of the impact of antecedent hydrological conditions on both the states and the transitions. This framework was developed to model the ecological outcomes of particular river-flow scenarios, and summarised the ecological knowledge required for maintenance or recovery of 'healthy condition' of floodplain vegetation. Recruitment was not explicitly included in the model, partly due to the rudimentary knowledge-base concerning recruitment of all vegetation elements, and partly under the assumption that vegetation in a healthy state will successfully recruit. Additionally, although the model does not include reproductive processes for the vegetation elements described as 'Forests and Woodlands', if the vegetation elements described as 'Benthic Herblands' and 'Shrublands' are provided for, it will probably provide recruitment opportunities for 'Forests and Woodlands', and therefore the five key species investigated in this review. Overton et al. (2014) state that testing is required to determine if the preference curves developed for the Southern Basin hold for the Northern Basin river systems (e.g. the systems are more dynamic; the Ecological Element 'E. largiflorens woodlands' might need to be replaced by 'E. coolabah woodlands').

2. METHODS

2.1. RESOURCES

This is a review of the literature concerning the water-requirements of key floodplain vegetation (*Eucalyptus camaldulensis, E. largiflorens, E. coolabah, Acacia stenophylla* and *Duma florulenta*) that occur in the Murray-Darling Basin. This information can be used to inform the Northern Basin Review, but (largely because of the paucity of information that originates in the Northern Basin) it has used information and resources from the whole of the Murray-Darling Basin. The review was done over a short period of time (c. 2 months), and although it targeted published and unpublished studies conducted since Roberts and Marston's review in 2011 (Roberts and Marston 2011) earlier sources of information have also been accessed.

This project involved a desk-top review of the literature and consultation with subject-matter experts and interested stakeholders. Initial interviews were held with a wide range of stakeholders in person and via telephone and email, allowing each to provide resources and inform the process. Face-to-face meetings were undertaken in Brisbane, Wentworth, Mildura, Adelaide, Benalla, Canberra and Ballarat. Telephone and email contact was made with other researchers, and staff of organisations that undertake monitoring, and managers, based in Queensland, Victoria and New South Wales (see appendix A for a list of the people with whom consultation took place). These meetings were designed to inform the stakeholder community about the literature review, obtain information and resources from those people, and establish mechanisms for on-going consultation.

Documents were obtained via the internet through a number of search engines (e.g. Google Scholar, Wiley-online, Elsevier, Scopus etc.), and by accessing documents deposited in institutional and personal archives. Many people provided copies of published and unpublished reports and theses from their personal libraries.

A workshop was undertaken in Brisbane (16-17 July 2015) to review the findings of this report, discuss the outcomes and identify knowledge gaps. The comments of the workshop participants have been taken into consideration in the preparation of this report; where information was used in this report, but an individual participant was not identified, the reference is given as 'Workshop 2015'.

2.2 REPORT STRUCTURE

This report is divided into an introduction dealing with general knowledge and premises concerning floodplain vegetation, then chapters concerning each of the species (or subspecies). The water regime requirements are described, and the life-histories of the species are illustrated.

Chapter 3 deals largely with *E. camaldulensis* subsp. *camaldulensis* as there are few references to other subspecies of *E. camaldulensis* that occur in the Murray-Darling Basin. Chapter 4 deals with *E. largiflorens*, Chapter 5 with *E. coolabah* subsp. *coolabah*, Chapter 6 with *Acacia stenophylla* and Chapter 7 with *Duma florulenta*. These chapters are followed by a chapter with summary tables for these key species (Chapter 8). The concept of Water Plant Functional Groups, and how they have been used with reference to these key species is discussed in Chapter 9, and the comprehensive raw-data tables referencing all the individual resources used to develop the life history diagrams are included in Chapter 10. Knowledge gaps identified in this study are outlined in Chapter 11. All of the resources used are referenced at the end of the document. An appendix with the names and affiliations of the workshop attendees and workshop summaries by the facilitator (Dr K. Muller) and the author (Dr M.T. Casanova) are included (Appendix A). Copies of all the resources used in this study have been deposited with Kelly Marsland at MDBA.

3. RIVER RED GUM: *EUCALYPTUS CAMALDULENSIS*

River Red Gum (*Eucalyptus camaldulensis* Dehnh.) has one of the widest natural distributions of any Australian tree species, and it is the least drought-tolerant of the floodplain tree species in this review (Doody *et al.* 2014). Seven sub-species have been recognised (McDonald *et al.* 2009) on the basis of genetic and morphological features. Prior to that revision, variants were recognised but there were differences in the number of sub-taxa delineated, and poor uptake of the nomenclature (Butcher *et al.* 2009). Three subspecies occur within the Murray-Darling Basin, and four occur elsewhere, in the Northern Territory and Western Australia. Subspecies *camaldulensis* appears to be confined to the Murray-Darling Basin, mainly south of the Queensland border but extending into Queensland on the Condamine River; subspecies *acuta* is common in the upper Darling Basin, especially north of the Queensland border; and subspecies *arida* is generally confined to areas west of the Paroo River (and outside the Murray-Darling Basin), with sporadic occurrences in the upper Darling Basin (north-west of Cobar, near Mount Gap Station). Given the apparent rarity of subspecies *arida* it will not be dealt with further in this review. The genetic variation among all sub-taxa is mirrored by variation in the environments where the sub-taxa grow (Butcher *et al.* 2009), especially in annual rainfall and evaporation. This suggests that there will be variation in the tolerance and responses to water regime by the different subspecies. Although separate subspecies were not identified by Dillon *et al.* (2014), they found that there were genetic differences among different populations of *E. camaldulensis* (which, on the basis of their sampling locations, certainly included different subspecies). They found that selection in response to climate has driven genetic differences (and presumably evolution of subspecies) at the landscape scale (Dillon *et al.* 2014).

The two subspecies *camaldulensis* and *acuta* are readily distinguished, although in previous studies (Brooker and Kleinig 2004; Boland *et al.* 2006) *Eucalyptus camaldulensis* subspecies *acuta* was thought to be a hybrid between *E. camaldulensis* and *E. tereticornis* (McDonald *et al.* 2009). The subspecies differ in a number of morphological features, including the shape of the operculae, the distribution of textured bark and the shape of the stamens in the bud (McDonald *et al.* 2009). A potential indicator of physiological differences, and differences in water requirements, is the distribution of veins in the leaves (in subsp. *acuta* it is dense, in subsp. *camaldulensis* it is sparse). This feature is conservative (i.e. all individuals within the subspecies retain the feature). Leaf venation (density of veins) is correlated with the shade-tolerance of plants, and the water availability and temperature regimes of plant habitats (Sack and Scoffoni 2013). A review of the extensive literature concerning leaf venation is outside the scope of this study, however, species from dry habitats tend to have smaller leaves, with greater vein length per unit area, which is thought to confer drought tolerance (Sack and Scoffoni 2013). The size of the juvenile leaves and the capacity to develop lignotubers varies among the subspecies (lignotubers sometimes present subsp. *acuta,* absent in subsp. *camaldulensis*), and these characteristics are also likely to impart physiological or adaptive differences. McDonald *et al.* (2009) recognised good support for genetic divergence between south-eastern Australian subsp. *camaldulensis* and Queensland subsp. *acuta*. There does not appear to be the creation of ‘genetic bottlenecks’, or highly isolated genotypes in populations even during extended drought (Dillon *et al.* 2015).

Eucalyptus camaldulensis occurs in at least two community types: floodplain forests and riparian woodlands (Roberts and Marston 2011). Forests have a higher tree density than woodlands, and the trees have fewer low branches, and are less spreading than woodland trees (Roberts and Marston

2011). Forests have developed in floodplain areas where flooding occurred at least once every two years. Woodlands, with trees with low branches and spreading habit, with a more open, grassy or shrubby understory, have developed where flooding occurred less frequently.

Eucalyptus camaldulensis has a seasonal phenology, mature plants will flower and set seed annually (although it takes 2 years from bud formation to seed release in most cases). This is in contrast to more opportunistic patterns of growth and reproduction displayed in species adapted to long-term scarcity of resources (Workshop 2015). The vast majority of studies on subsp. *camaldulensis* have been undertaken in the Southern Basin, in Victoria and South Australia.

A comprehensive summary table with references is provided in chapter 10 (Table 12. Ecological water requirements for *Eucalyptus camaldulensis*: processes, drivers and stressors.).

3.1 GENERAL REQUIREMENTS

Tables in Chapter 8 summarise the water regime required for the maintenance or recovery of condition for *Eucalyptus camaldulensis* subspecies *camaldulensis* floodplain forest (Table 1) and open woodland (Table 2), the water regime required for recruitment and regeneration of this species (Table 7), and additional factors that affect these communities (Table 8). These summary tables are based on the information detailed in this chapter. A life history diagram is provided in Fig. 4.

Eucalyptus camaldulensis subspecies *camaldulensis* can use rain water, river water or groundwater at different times in its life history (Doody *et al.* 2014; Doody *et al.* 2015), however, different sources of water can support different life history stages. Surface water (from rainfall or flooding) is essential for recruitment, but both surface water and groundwater can support adult trees. Groundwater should be fresh, but can be moderately saline. River water can infiltrate into the local groundwater via lateral bank recharge during periods of high flow and overbank flooding (Doody *et al.* 2014; Doody *et al.* 2015) and this is an important mechanism providing water for the maintenance of vegetation (Doody *et al.* 2014). Bank-full or preferably overbank flows are recommended to occur once every three years to maintain vigorous growth (Roberts and Marston 2011). Wen *et al.* (2009) recommended inundation once every five years to maintain condition. Flooding at lower frequencies leads to a decline in tree condition (Cunningham *et al.* 2009b; Overton and Doody 2009).

Eucalyptus camaldulensis subsp. *camaldulensis* has considerable capacity for water regulation (Doody *et al.* 2015), minimizing stress by reducing sapwood area and water use, by regulating stomatal conductance when water is scarce, and increasing sapwood growth and water use when water is in sufficient supply. Trees can also increase root density in the upper soil profile in response to overbank flooding, to increase water uptake (Doody *et al.* 2015). The environment (characterised by flood return interval) is likely to provide a strong selection pressure for trees with differing tolerance of water-stress.

3.2 FLOWERING SUCCESS IS INFLUENCED BY WATER REGIME

In the southern Murray-Darling Basin there is usually annual development of the inflorescences (including development of the pollen and egg cells), but the amount of flowering (yield) is dependent on water availability 24–36 months prior to seed fall (17–29 months before flowering) (Jensen *et al.* 2007). Buds are formed 9–13 months before flowering occurs (Dexter 1978; Colloff

2014), and water is required in December to February for ‘bud-set’ (Jensen *et al.* 2007; Jensen *et al.* 2008). Retention of buds requires average or above average rainfall in autumn (in the Southern Basin) (Jensen *et al.* 2007). Inflorescences can appear in November (Dexter 1978) and the main flowering period in subspecies *camaldulensis* is from December to January (Clemson 1985; Birtchnell and Gibson 2006; Butcher *et al.* 2009). Heaviest flowering events occur on a 2-year cycle (McDonald *et al.* 2009). Flowering intensity varies spatially (Jensen *et al.* 2008) and is likely to be flood-induced (Rogers and Ralph 2011).

Pollination is by insects, bats and birds (Butcher *et al.* 2009).

3.3 SEED PRODUCTION IS INFLUENCED BY WATER REGIME

A tree needs to be in adequate condition for flowering to occur and seed to be set (Workshop 2015). Large floral displays and high flowering success do not necessarily imply abundant seed production (Dexter 1978). Seeds mature about 9 months after flowering (Dexter 1978). Retention of capsules requires above average rainfall (Jensen *et al.* 2007; Jensen *et al.* 2008), and seed is retained in capsules on the tree for up to 2 years (George 2004). This is referred to as an aerial seed bank or serotiny. Seed fall (i.e. release of seeds from capsules) varies geographically (Jensen *et al.* 2008) and seasonally (Dexter 1978). It is possibly flood-induced (George 2004). In the Murray basin there are peaks in seed fall in Spring (Dexter 1978; George 2004) and Autumn (George 2004), and seed-fall is lowest in Winter (Dexter 1978). Number of seeds per tree can exceed 600,000 (Jacobs 1955), or be considerably less (George *et al.* 2005). Trees in poor condition (a result of drought or damage) retain seed longer than trees in good condition (George 2004), and trees in good condition produce more seed (George 2004).

Seed predation by ants can be important in removing seed from the floodplain (Meeson *et al.* 2002). It can occur throughout the year, and ant predation is modified by land-use (Meeson *et al.* 2002).

3.4 SEED DISPERSAL IS INFLUENCED BY WATER REGIME

Seeds are stored in the canopy until the capsules dehisce (open) and the seeds fall out. The primary mechanisms of *Eucalyptus* seed dispersal are usually gravity and wind (Turnbull and Doran 1987), but *E. camaldulensis* seeds are dispersed by water as well. Most seed falls within a distance of twice the height of the tree (Boomsma 1950), but flooding can disperse *E. camaldulensis* seed much further, as can pumped water from environmental watering (C. Campbell personal communication). Seeds can float for 10 days (Pettit and Froend 2001), stranding in lines as the water retreats (Jensen 2008). Flooding for too long (probably in excess of 10 days, although the length of time is not specified) can destroy seeds (Rogers and Ralph 2011), but flooding can mitigate predation by ants (Meeson *et al.* 2002) and other insects (Jacobs 1955). There is no evidence that *E. camaldulensis* in the Murray-Darling Basin forms a persistent, long-lived bank of seeds in the soil (Holland *et al.* 2013).

3.5 GERMINATION IS INFLUENCED BY WATER REGIME

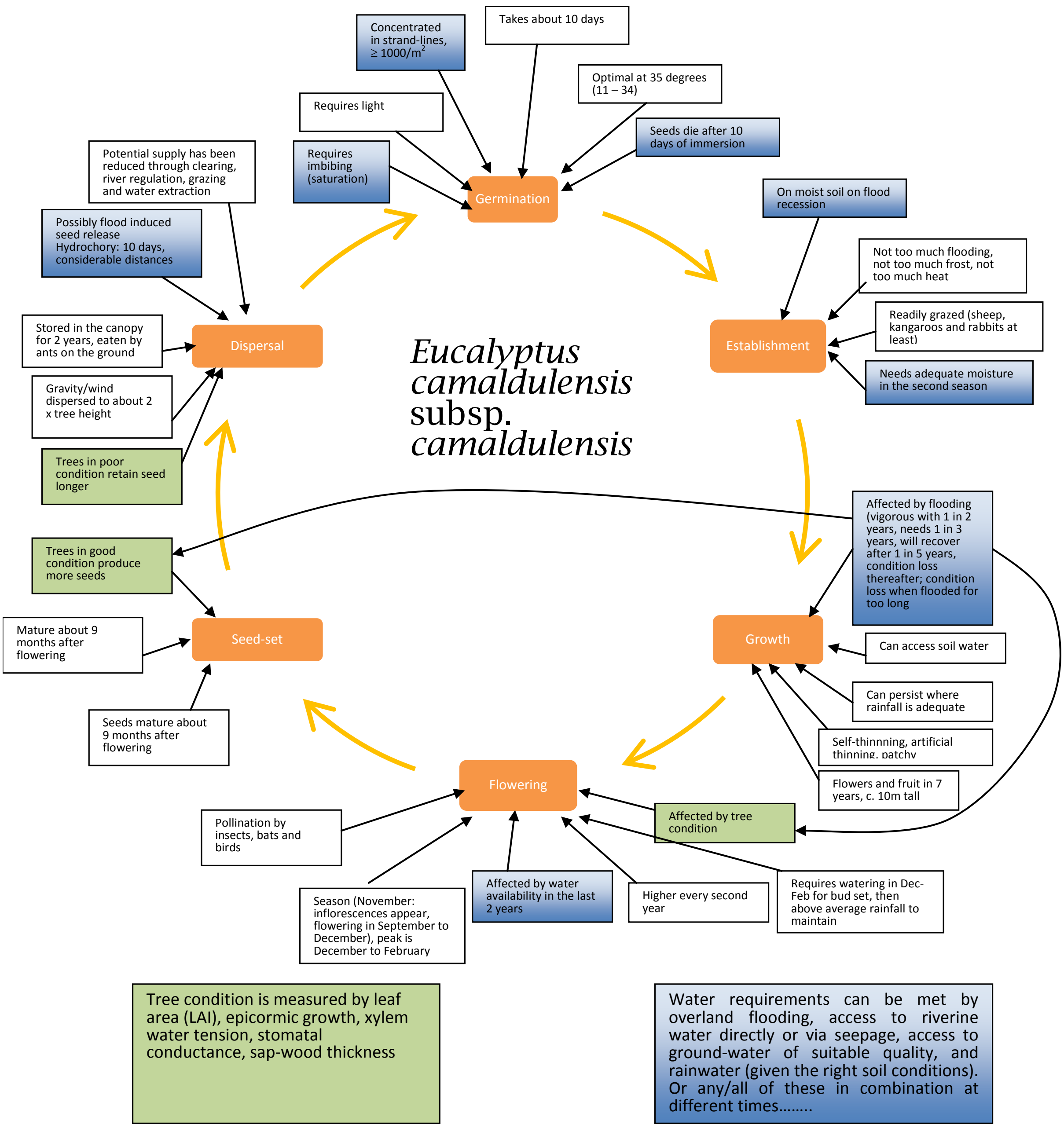

Figure 4. Life history diagram for *Eucalyptus camaldulensis* subsp. *camaldulensis* based on the information cited in Table 12 (chapter 10). Blue boxes are those that are influenced by water availability, green boxes are those that indicate an influence by tree condition.

As with most plants, germination of *E. camaldulensis* depends on adequate light, moisture and temperature (Dexter 1978). The seed needs to land on moist soil (Workshop 2015). Grose and Zimmer (1958) found the optimal temperature was c. 35 °C (occurring between 11–35 °C, but not below 8 °C), and it is likely to be enhanced by fluctuating temperatures. Winter conditions can expose germinants to unfavourably cold temperatures (Dexter 1978). Germination is higher in the light (70%) compared to the dark (5%) (Grose and Zimmer 1958). In the field germination is greatest where there is widespread flooding in Spring or early Summer (Pettit and Froend 2001 in a study on Western Australian subspecies), and larger numbers are stimulated to germinate after natural flood events compared to artificial watering (Holland *et al.* 2013). Densities can exceed 1000 m^{-2}. Germination success depends on seed condition (and conditions during seed development: Workshop 2015).

3.6 ESTABLISHMENT IS INFLUENCED BY WATER REGIME

Seedling establishment and growth of *E. camaldulensis* occurs on moist soil as floodwaters recede (Dexter 1967). Canopy gaps, patches of bare soil and a lack of competition can enhance establishment success (Workshop 2015). The young seedlings are susceptible to moisture stress and heat (George 2004; Jensen *et al.* 2008), as well as prolonged flooding (Argus *et al.* 2015) and cold (Rogers and Ralph 2011). Grazing of seedlings by kangaroos, sheep, cattle and rabbits causes mortality, and is increased during drought (Dexter 1978; Meeson *et al.* 2002). Within a year seedlings can produce roots that are up to a metre long (Colloff 2014), and stems to 4 cm in diameter (Colloff 2014). Resilience to disturbance increases with size, so that flooding can be tolerated longer (Dexter 1978), and leaves can be shed in order to develop longer roots if conditions are dry (Dexter 1978). If germination occurs in response to rainfall (Jensen *et al.* 2007), sufficient follow-up rain or flooding must occur to support the seedlings (Jensen *et al.* 2007; Jensen *et al.* 2008). There is little establishment of seedlings under mature trees (Colloff 2014), and self-thinning of stands removes 40–60 % of recruits over time (George 2004). In general there is patchy recruitment, dependent on local soil moisture, nutrient levels, grazing and ground cover (Taylor *et al.* 2014).

3.7 CONTINUED SURVIVAL DEPENDS ON WATER REGIME

Water requirements for tree growth are incompletely known (Doody *et al.* 2015). Flooding every 1–3 years for 5–7 months were estimated as the requirement for forests, and every 2–4 years for 2–4 months for woodlands (Roberts and Marston 2011); or winter-spring flooding every 1–3 years for 2–8 months (Rogers and Ralph 2011). Young trees of *E. camaldulensis* can reach 10 m tall in 6–7 years (Colloff 2014), and start to produce flowers and fruit. For vigorous growth trees require access to floods or bank recharge (Holland *et al.* 2011) at least once every 3–5 years (3: Roberts and Marston 2011; 5: Wen *et al.* 2009 for the Murrumbidgee). Duration of flooding should be from 2–8 months (Wen *et al.* 2009; Young 2001; Roberts and Marston 2011; Rogers and Ralph 2011), unless there is another source of water. Season of flooding should be Winter-Spring (Rogers and Ralph 2011), although this information comes from studies in the Southern Basin. It is quite possible that flooding in Summer is still useful for trees in the Northern Basin, since that region naturally experiences higher Summer rainfall. Trees can live 500 years or more (Colloff 2014), some authors put it as long as 1000 years (Jacobs 1955). Mature trees experience mortality due to decline in condition over time (Cunningham *et al.* 2011; Overton and Doody 2009).

There are standardised measures of tree condition, both via on-ground survey and using remote technologies (Cunningham *et al.* 2009). Leaf area index, crown density, extent of die back and epicormic growth and appearance of the tree (cracks in bark) give a standardised measure of tree condition (Souter *et al.* 2010; MDBA 2012b). The Normalised Difference Vegetation Index (NDVI) is used remotely to assess stand or community condition (Cunningham *et al.* 2009; Cunningham *et al.* 2011; Doody *et al.* 2015; Colloff *et al.* 2015; Fu and Burgher 2015). For *E. camaldulensis* a leaf-area index of 0.5 was identified as a threshold indicator of severe stress (Doody *et al.* 2015). Trees have adaptations (e.g. the capacity to regulate transpiration rate, and growth of sapwood and roots) that allow them to persist in different soil-moisture zones on a floodplain (Doody *et al.* 2015). Hydrological connectivity with the river channel is important for maintaining adult tree condition during prolonged drought (Doody *et al.* 2014). Both less frequent flooding (than suggested above: Cunningham *et al.* 2009; Overton and Doody 2009) and flooding longer than 60 days (under specific conditions), has been found to cause a decline in tree condition (Doody *et al.* 2014), but tree response is dependent on tree condition prior to flooding (so recommendations of flooding for 2–8 months (above) is likely to be dependent on prior soil saturation and tree condition). Continuous inundation of two or more years can be tolerated in some situations (Roberts and Marston 2011). The state and transition modelling of Overton *et al.* (2014) provides a summary of the different definitions of tree condition, and transitions between different condition states.

3.8 CONDITION AND RECOVERY FROM DROUGHT

There has been some long-term condition monitoring of *E. camaldulensis* through The Living Murray monitoring, and the Long-Term Intervention Monitoring of the Murray-Darling Basin (Gawne *et al.* 2013). The occurrence of the Millennium Drought in the Murray-Darling Basin (c. 1997–2010) and the 2010-11 floods allowed assessment of recovery, and duration of recovery following both natural and artificial watering. Preliminary data are starting to be available in this study. Tree condition improved in response to flow in the some parts of the Southern Basin, but improvement appears to have been short-lived, with some condition metrics returning to pre-watering values within 2 years (Ebsworth and Bidwell 2013; Bidwell and Wills 2015; Bidwell and Simoung 2015). The greatest improvement in tree condition was found in sites that received a ‘long’ flood duration (Bowen *et al.* 2012) , although the length of time was not specified (possibly longer than 2 months). However, there can be a two-month delay in detectable recovery of trees after flooding is provided (Doody *et al.* 2014). In a landscape-scale assessment in the Macquarie Marshes, good condition scores were maintained in sites flooded at least 1 year in 2; persistence thresholds were strongly associated with annual flooding 4 years in 10, and recovery from drought was associated with annual flooding of more than 7 times in 10 years (Catelotti *et al.* 2015).

There is evidence that adult tree condition is predicted by hydrological models (see above: Catelotti *et al.* 2015) but annual rainfall, in combination with hydrology, was also useful in predicting tree health at Gunbower Island (Colloff *et al.* 2015). Models of tree occurrence that used both hydrology (riparian connectivity, groundwater depth, distance from weir) and land use (agricultural activity and grazing intensity) provided significant predictors (of tree occurrence, rather than condition) in the Northern Basin (Kath 2012). Kath (2012) found that the presence of small size-classes of *E. camaldulensis* was best predicted ($p < 0.05$) by hydrological parameters (recent groundwater depth and distance from weir (= exposure to flows), whereas larger size classes (> 20cm dbh) were best predicted ($p < 0.05$) when grazing intensity was included as a variable. It was thought that grazing intensity incorporated a range of historical land-uses that inhibited *E. camaldulensis* establishment or survival (Kath 2012). The extent to which trees have declined (low condition scores) impacts on the capacity of trees to respond to freshening of groundwater and channel flow. Healthy trees were three times more likely to respond than stressed trees and 30 times more likely to respond than defoliated trees (Souter *et al.* 2014). Stand condition has been found to decline progressively down the Murray River floodplain (Cunningham *et al.* 2009), and this was attributed to more extreme declines in natural flooding due to water harvesting, and the drier climate that occurs in the lower Murray region.

There has been debate about the importance of tree density in survival and recovery from drought. Dense stands of *E. camaldulensis* experience higher mortality under water stress than sparse stands (Horner *et al.* 2009), but thinning alone is not sufficient to retain community diversity (Horner *et al.* 2012). Stand structure was investigated as a potential factor influencing the extent of die-back in *E. camaldulensis* stands, however, large and small trees showed a similar reduction in probability of survival with decreasing stand condition, suggesting that forestry practices such as reducing stand density to improve tree condition are unlikely to mitigate dieback (Cunningham *et al.* 2010). Patchiness in the occurrence of die-back was more likely to be related to soil moisture (and groundwater) than stand structure (Cunningham *et al.* 2009; Cunningham *et al.* 2011).

3.9 SUBSPECIES *ACUTA*

Apart from the taxonomic reviews by Butcher *et al.* (2009) and McDonald *et al.* (2009) little information is available about *E. camaldulensis* subspecies *acuta* in the Murray-Darling Basin. This subspecies is characterised by the mainly smooth, white, cream or grey bark throughout, dense-reticulate venation on the leaves and characters of the flowers and fruit. The juvenile leaves are ovate to broad-lanceolate, and larger than for subspecies *camaldulensis* (McDonald *et al.* 2009). This species can also develop lignotubers, which would enhance recovery and persistence following disturbance (McDonald *et al.* 2009). Flowering of this species in the Northern Murray-Darling Basin occurs from October to November (Butcher *et al.* 2009; McDonald *et al.* 2009). Capon *et al.* (2012) report seeds retained in the canopy and on the ground, possibly for this subspecies, and there are incidental reports of seedlings recorded in the Northern Basin (again, possibly for this subspecies) (Capon *et al.* 2012; Capon and Balcombe 2015) (Table 13 in chapter 10).

4. BLACK BOX: *EUCALYPTUS LARGIFLORENS*

Eucalyptus largiflorens is recognised as a single species throughout the Murray-Darling Basin. It is largely confined to the Murray-Darling Basin with few outliers in northern Queensland, the Cooper Basin, coastal NSW and south of the Great Dividing Range in Victoria (Atlas of Living Australia www.spatial.ala.org). There is a hybrid between *Eucalyptus largiflorens* and *E. gracilis* locally called 'Green Variant' or 'Green Box' (Nicholls 2009; Parsons and Zubinich 2010) which tolerates salinity better than Black Box does, and uses water more conservatively (as a consequence of its mallee parentage). However, as it is an occasional element of the Murray floodplain (east to Moulamein and Deniliquin, west to Sedan), and not widespread across the Murray-Darling Basin (Parsons and Zubinich 2010), it is not dealt with further in this review.

Like *E. camaldulensis, Eucalyptus largiflorens* has a seasonal phenology, with a two-year cycle from bud to seed (Fig. 5). However, the seasonality of this species could vary across the Murray-Darling Basin and the timing of life history events in the Northern Basin is not known (Workshop 2015).

A comprehensive summary table of information with references is provided in chapter 10 (Table 14. Ecological water requirements for *Eucalyptus largiflorens*: *processes*, drivers and stressors).

4.1 GENERAL REQUIREMENTS

Tables in Chapter 8 summarise the water regime required for the maintenance or recovery of condition for *Eucalyptus largiflorens* (Table 3), and the water regime required for recruitment and regeneration of this species (Table 7)), and additional factors that affect these communities (Table 8). These summary tables are based on the information detailed in this chapter.

Eucalyptus largiflorens occurs on grey, self-mulching clays of periodically waterlogged floodplains, swamp margins, ephemeral wetlands and stream levees (Commonwealth of Australia 2011). Communities containing *E. largiflorens* are described as 'flood-dependent woodland' in Bowen *et al.* (2012). *Eucalyptus largiflorens* is generally less tolerant of inundation than *E. camaldulensis,* but more tolerant of drought (Henderson 2011). There is evidence of decline in *E. largiflorens* in the southern Murray-Darling Basin (Hardwick and Maguire 2012) and the threats include clearing for cropping and altered flooding regimes, including too frequent and prolonged inundation from irrigation drainage, as well as insufficient water for establishment and maintenance (Hardwick and Maguire 2012). The species occurs as part of a Nationally Endangered Ecological Community (Coolibah-Black Box Woodlands) in Queensland and New South Wales, within the Darling catchment (Commonwealth of Australia 2011), and the Coolibah-River Cooba-Lignum Woodland of the Darling Riverine Plains (Namoi CMA 2012). It constitutes 'flood dependent woodlands' in the Gwydir (Bowen *et al.* 2012). *E. largiflorens* occurs in a number of ecological vegetation classes (EVCs) in Victoria (e.g. Black Box-Chenopod Woodland, Black Box Wetland). In Black Box Wetland (EVC 369) inundation occurs 8–10 years in 10 (i.e. almost annually), to 3–7 years in 10 (i.e. intermittently) (Frood 2012). Duration of flooding is 1–6 months (Frood 2012). *E. largiflorens* woodland provides habitat to a range of other flora and fauna (McKenny *et al.* 2014).

In contrast to the assertion that *E. largiflorens* does not represent a significant component of the vegetation in the Queensland Murray-Darling Basin (Marshall *et al.* 2011; Holloway *et al.* 2013) a very brief search of herbarium data for Queensland (2.4% of all records = 146 gatherings) provided records of its occurrence in the Queensland Murray-Darling Basin described as 'very common' or 'dominant' on areas of the floodplain (Atlas of Living Australia www.spatial.ala.org), as well as in association with *E. camaldulensis* and *E. coolabah*. This suggests that the 'Regional Ecosystem mapping' on which Marshall *et al.* (2011) and Holloway *et al.* (2013) relied to determine its contribution to Queensland floodplains might need to be updated.

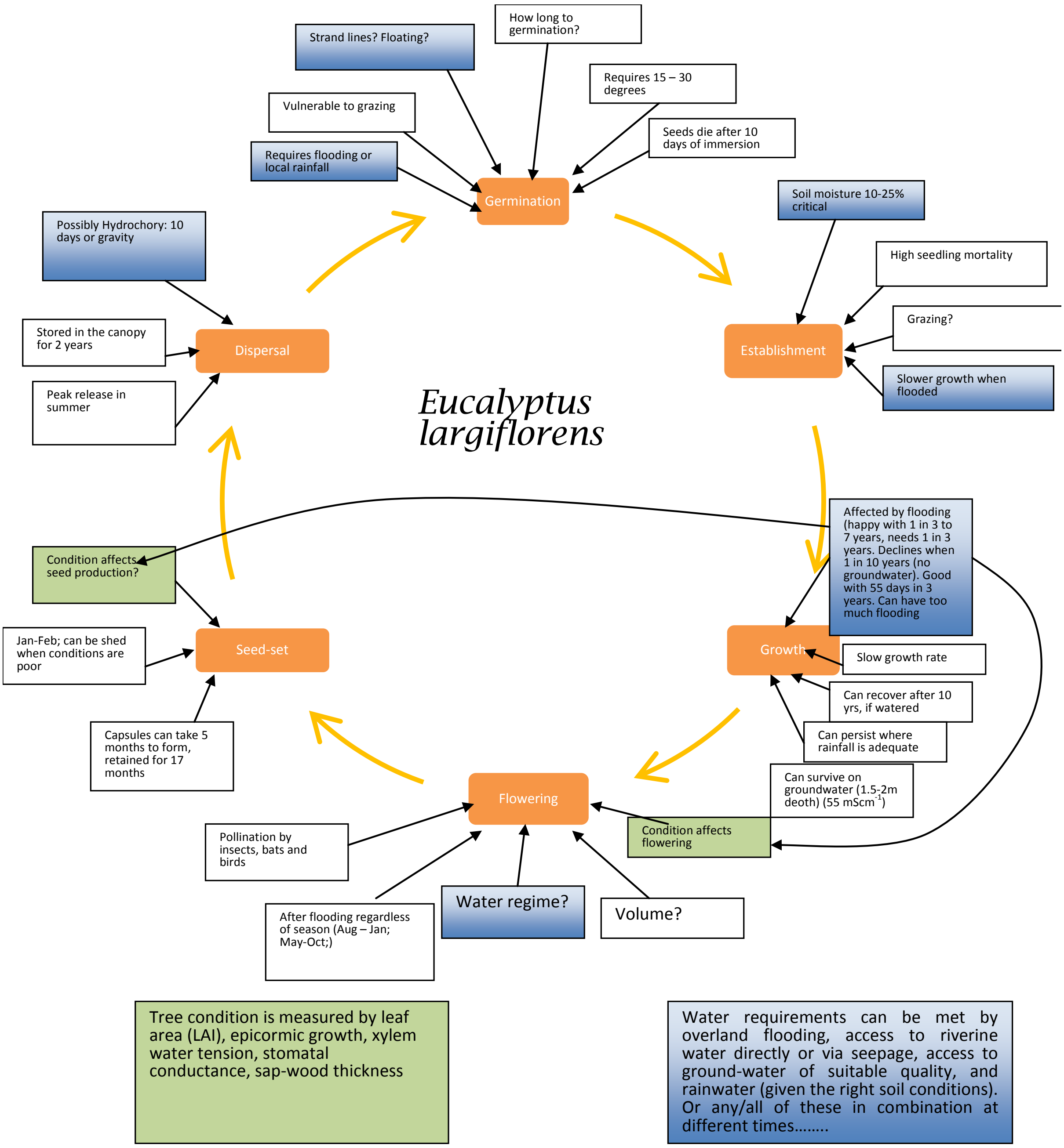

Figure 5. Life history diagram for *Eucalyptus largiflorens* based on the information cited in Table 13. Blue boxes are those that are influenced by water availability, green boxes are those that indicate an influence by tree condition.

4.2 FLOWERING IS INFLUENCED BY FLOODING

Eucalyptus largiflorens can flower more than once a year (Parsons and Zubrinich 2010), in response to flooding, irrespective of season (Cale 2009), and sometimes over an extended period (George 2004; Jensen 2008). However, the amount of flowering is dependent on tree condition (George 2004).

4.3 SEED PRODUCTION IS INFLUENCED BY FLOODING

Eucalyptus largiflorens sheds seed from January to February (Jensen 2009), but bud and fruit can be shed when conditions are not optimal (Jensen 2009). Seed production is dependent on tree condition and prior season watering (Jensen *et al.* 2008), and capsules can take up to five months to form (George 2004).

4.4 SEED DISPERSAL MIGHT BE INFLUENCED BY FLOODING

Seed of *E. largiflorens* is stored in the canopy for up to 2 years (Jensen *et al.* 2008; Jensen 2009) but what triggers capsule dehiscence is unknown (Gehrig 2013). Fire and flooding are candidates for the stimulus (Jensen *et al.* 2008), and peak seed release is in the summer (Jensen *et al.* 2008). Gravity or hydrochory are responsible for dispersal (Roberts and Marston 2011), and *E. largiflorens* can form strand-lines of established saplings after floods.

4.5 GERMINATION AND ESTABLISHMENT REQUIRE FLOODING OR LOCAL RAINFALL

Germination of *E. largiflorens* is episodic (Duncan *et al.* 2007) and requires flooding and/or local rainfall (Jensen *et al.* 2008; Jensen 2009). Temperature for germination can be between 15 and 30 °C (Magann *et al.* 2012), indicating that Summer is probably optimal (Gehrig 2013). Germination usually occurs after natural flooding events (Holland *et al.* 2013), but few seedlings were recorded after regional floods in the Northern Basin (Capon and Balcombe 2015). Establishing seedlings are generally vulnerable to grazing (Duncan *et al.* 2007), intolerant of drought (Llewelyn *et al.* 2014), but also experience slow growth when flooded to a depth of 5 cm (Heinrich 1990). Soil moisture of 10-25 % appears to be critical for seedling survival (Jensen 2009). The requirement for a ‘Goldilocks-zone’ of ideal conditions (i.e. not too wet, not too dry) for establishment means that *E. largiflorens* can experience high seedling mortality (Doody and Overton 2012).

4.6 GROWTH AND MATURITY IS INFLUENCED BY AVAILABLE WATER

Eucalyptus largiflorens has a slow growth rate due to low transpiration rates (Roberts and Marston 2011; Holland *et al.* 2011). This makes the species somewhat hardier than *E. camaldulensis* and explains its distribution higher on the floodplain. Tree condition is impacted by both too much and too little flooding (Hardwick and Maguire 2012). Trees are known to survive on local rainfall (Jensen *et al.* 2008), and by using groundwater (Doody *et al.* 2009b; McGinness *et al.* 2013; Arthur *et al.* 2011), but trees benefit from floodwater (once every 3–7 years: Roberts and Marston 2011; for 2–6 months: McGinness *et al.* 2013; once every 4–5 years for 4–6 months: Slavich *et al.* 1999), or from artificial watering (80 mm month^{-1}: Llewelyn *et al.* 2014). Trees can use groundwater at depths of 1.5–2 m (Gehrig 2013), although Colloff *et al.* (2015) suggest > 3.65 m is a threshold for good health, but such assessments are dependent on the salinity of the groundwater and the tree’s access to other sources of water. Trees can be tolerant of groundwater salinity up to 55,000 µS cm^{-1}. Where groundwater is good quality (< 32,000 µS cm^{-1}: Colloff *et al.* 2015) and easily accessed, overbank flows are less important for tree survival (McGinness *et al.* 2013).

The relationship between *E. largiflorens* and groundwater is complex, and dependent on both depth to groundwater and groundwater salinity. Rainfall and overbank flooding, as well as proximity to floodrunners and channels complicate the relationship, because like most floodplain vegetation, *E. largiflorens* is opportunistic in obtaining water (Workshop 2015).

Recovery from drought can occur through epicormic growth (Doody *et al.* 2014), resulting in an increased leaf area index (Overton and Jolly 2004). Recovery can persist for up to 10 years following flooding (Overton and Jolly 2004). Artificial watering can restore health via bank-recharge and groundwater freshening (Holland *et al.* 2009), but where groundwater tables have fallen, rainfall is in deficit and flooding occurs less than 1 in 2 years, trees will be in poor condition and more likely to die than where groundwater tables are accessible, or rainfall is sufficient (McGinness *et al.* 2013).

5. COOLIBAH: *EUCALYPTUS COOLABAH* SUBSPECIES *COOLABAH*

Eucalyptus coolabah was part of a group in genus *Eucalyptus* revised by Hill and Johnson (1994) resulting in eight species including *E. coolabah* with three subspecies. Two of these subspecies occur on floodplains in the Murray-Darling Basin (subspecies *coolabah*: on flat, heavy soil plains; and *excerata*: in headwaters, in rolling country and sandy floodplains), and the third subspecies *arida* occurs in Central Australia and the Cooper basin (Hill and Johnson 1994). This review will be concerned largely with subspecies *coolabah* because few studies distinguish the subspecies, and there is little information about the group as a whole.

Coolibah-Black Box communities have declined in area since European habitation, and the rate of loss appears to have accelerated in recent years (Keith *et al.* 2009). As a consequence, Coolibah-Black Box communities are listed as endangered under the EPBC Act (1999) and NSW legislation, with the note that the community is likely to become extinct unless threats are abated. Until recently, regrowth was permitted to be cleared (Good *et al.* 2012). There is now recognition that dense regeneration of *E. coolabah* in grasslands is likely to be a natural phenomenon that progresses towards the conditions found in remnant *E. coolabah* woodlands (Good *et al.* 2012).

A comprehensive summary table with references is provided (Table 15. Ecological water requirements for *Eucalyptus coolabah*: processes, drivers and stressors). A life history diagram is provided (Fig. 6).

5.1 GENERAL REQUIREMENTS

Tables in Chapter 8 summarise the water regime required for the maintenance or recovery of condition for *Eucalyptus coolabah* (Table 4), and the water regime required for recruitment and regeneration of this species (Table 7), and additional factors that affect these communities (Table 8). These summary tables are based on the information detailed in this chapter.. These requirements are based on the information described in this chapter.

Eucalyptus coolabah can occur in a diversity of riparian habitats, at the top-of-bank, on extensive floodplains and can co-occur on grey, self-mulching clays of periodically waterlogged floodplains, swamp margins, ephemeral wetlands and stream levees in association with other species (e.g. *E. largiflorens*) as endangered Coolibah–Black Box Woodland (Commonwealth of Australia 2011; Roberts and Marston 2011). It is generally thought to be less reliant on floods than the other floodplain *Eucalyptus* species. Its distribution (largely in the north of the Murray-Darling Basin, and (with its other subspecies) into the arid zone) means that it is, so far, much less studied than other floodplain eucalypts.

5.2 FLOWERING

Flowering of *E. coolabah* in the Cooper Basin (possibly subsp. *arida*) occurs between late summer and early winter (Roberts and Marston 2011), and varies among regions and years (Pettit 2002). Flowering success is likely to be dependent on tree condition (Roberts and Marston 2011).

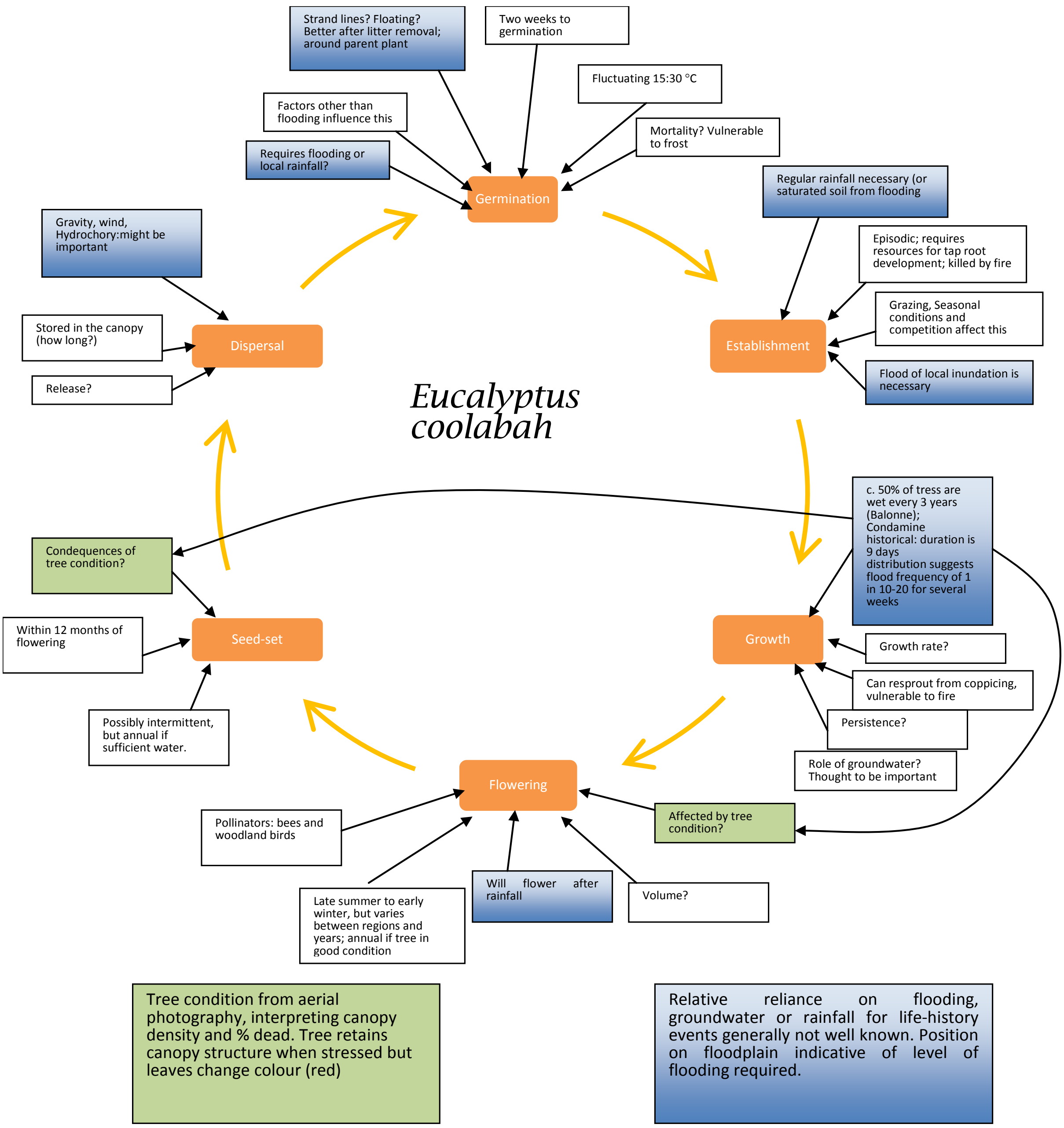

Figure 6. Life history diagram for *Eucalyptus coolabah* based on the information cited in Table 14. Blue boxes are those that are influenced by water availability, green boxes are those that indicate an influence by tree condition.

5.3 SEED PRODUCTION AND DISPERSAL

Bud and seed development might be intermittent, rather than annual (Roberts and Marston 2011). Viable seed is stored in the canopy, and is not long-lived once the fruit dehisces (Doran and Boland 1984).

5.4 GERMINATION

Doran and Boland (1984) record 35 °C as optimal for *E. coolabah* (although this was probably a mix of subspecies, and not *E.coolabah* subsp. *coolabah*), but germination tests for the Kew Millennium Seed Bank resulted in 100% germination at 15 °C and 90% at 20 °C (D.Duval, personal communication). Vincent (2012) found that optimal germination of *E. coolabah* occurred in fluctuating day:night temperatures of 15:30 °C and 30:20 °C whereas constant temperatures did not enhance germination. Leaf litter deposited prior to seed fall had a positive impact on seed germination, in experiments that ran for 15 days, achieving up to 90% germination (Vincent 2012). Seedlings are generally rare, although dense patches do occur (Capon and Balcombe 2015), but when found they were widespread (not abundant) after the 2011 flood, (Capon *et al.* 2012). Floods are more common than recruitment, so other factors are likely to play a role in stimulus of germination or success of establishment (Good 2012). It is likely that wet soils, or shallow flooding in late summer are required for germination (Foster 2015).

5.5 ESTABLISHMENT AND GROWTH

Eucalyptus coolabah seedlings have variable growth rates, and their abundance in the field is negatively related to the length of the flood event (i.e. longer floods, fewer seedlings) (Capon *et al.* 2012). Although there was extensive regeneration following floods in the 1970s, establishment appears to be episodic in response to rare climatic conditions (Good 2012). Seedling survival was affected more by seasonal conditions and herbivory than by competition with grasses (Good *et al.* 2011; Good 2012), and although it appears that regular rainfall is required for establishment (Good 2012), saturated soil conditions following flooding might be sufficient (Freudenberger 1998). Shade and/or thermal protection is required for establishment (Good *et al.* 2014). Seedling regeneration can be dense (c.f. Capon *et al.* 2012), and self-thinning occurs as the stand matures (Good 2012).

On a landscape scale, *E. coolabah* open woodlands on the Balonne floodplain (Cullen *et al.* 2003; when the Balonne River had not yet experienced the impacts of potential diversions) had at least 50% of their total area wetted (45,000 ML day^{-1}), on a return interval of c. 3 years, and the majority of the floodplain is full when 60,000 ML day^{-1} is recorded at St George (return interval of c. 3.6 years) (Cullen *et al.* 2003). The overall distribution pattern suggests a flood frequency of one in 10–20 years, with a likely duration of several weeks (Foster 2015), although Marshall *et al.* (2011) suggest a flood duration of 9 days. It has been suggested that surface flooding is not required to maintain vigour in mature trees, as they can access groundwater (Roberts and Marston 2011).

Eucalyptus coolabah communities that occur on the drier end of the floodplain are threatened by clearing, weed invasion and livestock grazing (Good 2012). To date there is no information about the recovery of *E. coolabah* from drought.

6. RIVER COOBA: *ACACIA STENOPHYLLA*

Acacia stenophylla is a small riparian tree with decumbent leaves and branches, that occurs throughout the Murray-Darling Basin, as well as into the Cooper Basin and the Northern Territory (Atlas of Living Australia: www.ala.org.au). It has a symbiotic association with bacteria in its roots that allows it to fix nitrogen. As a consequence, it is likely to be an important component of floodplain nutrient processes. It can co-occur with *E. coolabah* and/or *E. largiflorens* in floodplain communities, and at the top-of-bank with *E. camaldulensis*.

Tables in Chapter 8 summarise the water regime required for the maintenance or recovery of condition for *Acacia stenophylla* (Table 5), and the water regime required for recruitment and regeneration of this species (Table 7), and additional factors that affect these communities (Table 8). These summary tables are based on the information detailed in this chapter.. These requirements are based on the information described in this chapter.

A comprehensive summary table with references is provided (Table 16. Ecological water requirements for *Acacia stenophylla*: processes, drivers and stressors). A life history diagram is provided (Fig. 7).

6.1 SEEDS AND GERMINATION

Fruits mature in Spring to early Summer (Murray 2011), and the atypical *Acacia* pods (or *legumes*) disarticulate into 1-seeded parts. The seed is retained in the pod which provides a corky covering, allowing the seed to float. No differences in seed abundance have been recorded in relation to flood frequency or duration (Murray 2011). The seeds are dispersed by floodwaters, and possibly ants. Seeds are frequently found in strand lines. Germination of *A. stenophylla* seeds is comparable to that of other *Acacia* species, and is enhanced by nicking the seed coat (D.Duval personal communication), and treatment with hot water (M.Henderson personal communication). Seedlings can be common and widespread (Capon and Balcombe 2015), especially after the 2011 floods (Capon *et al.* 2012). Holland *et al.* (2013) report that germination is enhanced by natural flooding rather than artificial watering, presumably as a consequence of the greater duration and extent of flooding (Workshop 2015).

6.2 ESTABLISHMENT AND GROWTH

Acacia stenophylla is relatively hardy once established (Doody and Overton 2012), and can grow rapidly (Capon *et al.* 2012). The seedling density is negatively related to time since inundation (longer time, fewer seedlings) and positively related to the duration of the last flood event (longer duration, more seedlings) (Capon *et al.* 2012). *Acacia stenophylla* is tolerant of salinity although growth declines with increasing (high) salinity (0.6 to 16.67 dS cm^{-1}) (Sahito *et al.* 2013). Relative salinity tolerance is conferred via an increase in proteins, sugars, proline and secondary metabolites, and enhanced by a larger K/Na ratio (Sahito *et al.* 2013). Vegetative reproduction (via suckering) occurs frequently (NSW Government Information sheet). The transpiration rates that have been measured vary from 2–75 mm per year (Holland *et al.* 2011; Doody *et al.* 2013), and the species has a high tolerance of flooding, but a low tolerance of drought (Murray 2011).

Condition (as measured in plant height, crown diameter and stem diameter) was found to vary in relation to flood frequency, and plants were in best condition in high frequency/high duration zones (Murray 2011). Leaf characters were not significantly different among zones (Murray 2011), but there were more dead trees in low flood frequency/short duration zones (Murray 2011). In the lower Murray (SA) *Acacia stenophylla* competes with exotic *Salix* spp (Willows) for space (Workshop 2015). No information about tree recovery from drought was obtained in this literature review.

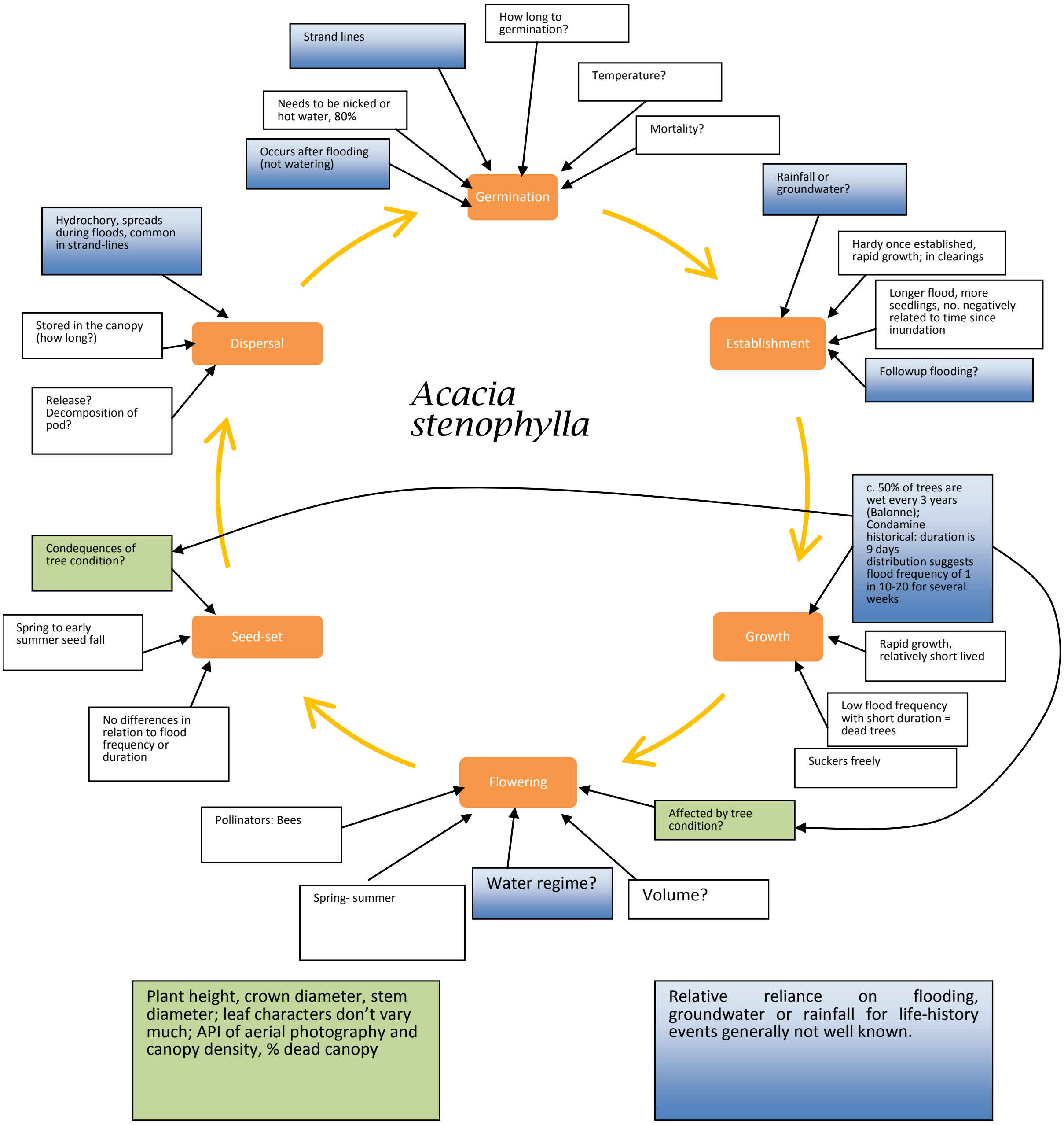

Figure 7. Life history diagram for *Acacia stenophylla* based on the information cited in Table 15. Blue boxes are those that are influenced by water availability, green boxes are those that indicate an influence by tree condition.

7. LIGNUM: *DUMA FLORULENTA*

Duma florulenta is multi-stemmed shrub that occurs throughout the Murray-Darling Basin on floodplains and wetlands. It is important nesting habitat for colonial nesting waterbirds and freckled duck (Foster 2015). Plants are dioecious (with separate male and female plants) and sometimes largely leafless (Hardwick and Maguire 2012). It was, until recently, referred to *Muehlenbeckia florulenta* and prior to that *Muehlenbeckia cunninghamii,* but recent taxonomic revision has placed it in a new genus, along with *D. horrida* and *D. cocolobioides* (Schuster *et al.* 2011).

Tables in Chapter 8 summarise the water regime required for the maintenance or recovery of condition for *Duma florulenta* (Table 6), and the water regime required for recruitment and regeneration of this species (Table 7), and additional factors that affect these communities (Table 8). These summary tables are based on the information detailed in this chapter.. These requirements are based on the information described in this chapter.

A comprehensive summary table with references is provided in chapter 10 (Table 17. Ecological water requirements for *Duma florulenta*: *processes*, drivers and stressors). A life history diagram is provided (Fig. 8).

7.1 DISTRIBUTIONAL REQUIREMENTS

Duma florulenta occurs as a dominant in wetland communities, and as understory in Black Box woodland on the Lower Murrumbidgee River (Hardwick and Maguire 2012). In the Murray it occurs as a dominant in shrublands, wetlands, and as a co-dominant or understory in *E. camaldulensis, E. largiflorens* and *Acacia stenophylla* woodlands (Henderson *et al.* 2011). It can co-occur with endangered Coolibah–Black Box Woodland on grey, self-mulching clays of periodically waterlogged floodplains, swamp margins, ephemeral wetlands and stream levees (Commonwealth of Australia 2011). Distribution patterns suggest a flood-frequency of one in ten to one in 20 years, of unknown duration (Foster 2015). In Victoria *D. florulenta* occurs in a number of Ecological Vegetation Classes (EVCs A101, 104, 657, 784, 808, 823, 954, 947; named e.g. Freshwater Lignum-Cane Grass Swamp, Brackish Lignum Swamp). The inundation regime for these EVCs is given as 'greater then 3–7 years in 10, dry between inundations, and durations usually 1–6 months (but not permanent)' (Frood 2012). In the Balonne it occurs mostly in floodplain wetlands that hold water for at least 90 days following flooding (Marshall *et al.* 2011). The most favourable conditions for lignum appear to be on open river flats with few trees, where flooding occurs about once every 3 -10 years (most at 3.5–6 year intervals). Soil characters are >15% moisture, < 1500 $\mu S cm^{-1}$, 5% organic matter content and pH of 5 (Craig *et al.* 1991). High soil moisture can compensate for high salinity soils (Craig *et al.* 1991). Prior to protection of this species there was substantial clearing of *D. florulenta* communities, this, combined with burning and lack of watering has resulted in severe (40%) depletion of the community in certain places (Hardwick and Maguire 2012). However, *D. florulenta* is not thought to be severely depleted throughout the Murray-Darling Basin as a whole (Workshop 2015).

7.2 REPRODUCTION, GERMINATION AND ESTABLISHMENT

Flowering occurs potentially in response to rain (Roberts 2001), but also in response to flooding; higher numbers of flowers/seeds are related to high frequency, short duration flooded habitats (Murray 2014). Seed is produced readily (Hardwick and Maguire 2012), and different frequency and durations of flooding do not precondition seeds for germination (Murray 2011). *D. florulenta* does not form a long-lived bank of seeds in the soil (Holland *et al.* 2013). The seeds are shed into the water or onto the soil if the site is dry, and remain buoyant for 5–25 days (Hardwick and Maguire 2012), (45 days A. Jensen personal communication). Seeds are transported by floodwaters (Hardwick and Maguire 2012; Capon *et al.* 2009; Chong and Walker 2005). Germination on damp soil occurs within 14 days of dispersal (Hardwick and Maguire 2012), or even while still floating (Capon *et al.* 2009; A. Jensen personal communication), and germination rates can be up to 95% under fluctuating temperatures (35/20 °C, and a light/dark photoperiod of 8/16) (D.Duval personal communication). If seeds fall on dry soil they are vulnerable to ant predation (A. Jensen personal communication). Germination and establishment occur naturally after flood events and less so after artificial watering (Holland *et al.* 2013). There are reports of continuous recruitment (Capon *et al.* 2012) although in some places season (late Summer to Autumn) appears to be critical for germination (Foster 2015). In a recent Northern Basin study, few seedlings were recorded (Capon and Balcombe 2015). Grazing of seedlings could influence recruitment, as they have been seen to be grazed by kangaroos (A. Jensen personal communication).

Seedlings are more tolerant of drying than flooding (Capon *et al.* 2009), and establishment can be rapid under experimental conditions (Holloway *et al.* 2013). Flooding slows growth and delays development (Capon *et al.* 2009), which leads to greater seedling establishment in drier areas, although at high elevations a lack of moisture can lead to dormancy in seedlings (A. Jensen personal communication). Exposure to drying induces a plastic response (leaf loss) in seedlings (Capon *et al.* 2009)

7.3 GROWTH AND MATURITY

Duma florulenta undergoes vegetative spread via arching stems, layering (Jensen 2006), rhizomes and stem fragmentation (Roberts and Marston 2011). Vegetative reproduction is common after flood, but not after rain (A. Jensen personal communication). Dispersal can also occur through vegetative means (Workshop 2015). Vegetative reproduction can be important in habitats that are flooded for long durations (Capon *et al.* 2009), as seedling survival is limited in those places (Murray 2011). An avoidance of continuous flooding, and avoidance of complete drying between floods is required to maintain best condition in *D. florulenta* (Foster 2015). Flooding, on average, once every 5 years for up to 7 months has been found to maintain condition (Hardwick and Maguire 2012).

7.4 CONDITION, PERSISTENCE AND RECOVERY FROM DROUGHT

A Lignum condition index has been developed (Henderson *et al.* 2011). During drought plants can survive via a persistent root stock, up to 3 m deep (Craig *et al.* 1991), and the plants become essentially dormant (Roberts and Marston 2011). Leaves are lost and plants appear to be lifeless (Doody and Overton 2012). There is a limit to the length of drought that *D. florulenta* can experience and still recover, and current research efforts are addressing this (C. Campbell personal communication). Although plants respond to rainfall, rainfall alone is generally insufficient to maintain stands in good condition (Henderson *et al.* 2011). Plants can regenerate within two weeks of being flooded (Craig *et al.* 1991). Condition is enhanced by widespread flooding (Doody and Overton 2012), and a high frequency of floods of short duration (c. 2 months) is best for *D. florulenta* (Murray 2011; Bowen *et al.* 2011).

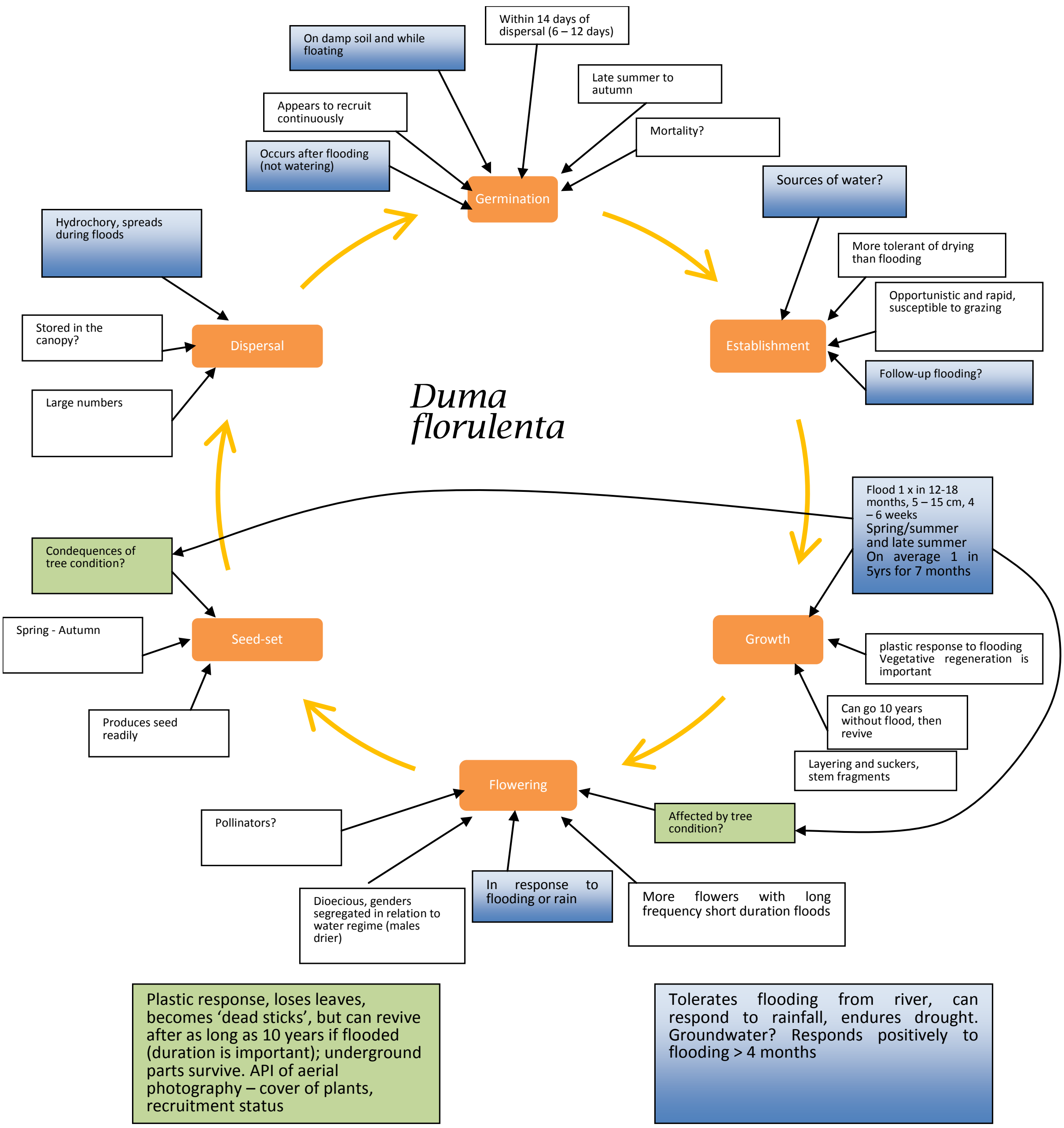

Figure 8. Life history diagram for *Duma florulenta* based on the information cited in Table 17. Blue boxes are those that are influenced by water availability, green boxes are those that indicate an influence by tree condition.

8. SUMMARY OF KNOWLEDGE

From information collected through this literature review, and the results of a workshop held in Brisbane to ascertain expert knowledge, the current knowledge of the ecological water requirements for five key species has been summarised in the following 8 tables. The information has been derived from Roberts and Marston (2011 and references therein), Kirby *et al.* (2013), the comprehensive tabulation of data for each taxon, based on this literature review (section 10) as well as the input of the experts who attended the workshop. There was much discussion about the term 'condition' in the workshop. Eventually, it was agreed that the state and transition model developed by Overton *et al.* (2014) (Figure 10) provides a better framework for describing and presenting vegetation responses. There is a defined relationship between state (i.e. condition of the plant ranging from '*good*' to '*critical*'), stress (primarily due to lack of water) and recovery (due to restoration of conditions for adequate growth) (Figure 10; see section 1.2) based on published preference curves and descriptive tables (Overton *et al.* 2014).

Overton *et al.* (2014) describe two transition pathways, a 'stress' pathway (decline from *Good*, through *Medium*, *Poor* and *Critical* to *Death*), and a 'recovery' pathway (back to *Good* via an *Intermediate* state) (Fig. 9). Note that the *Intermediate* state in *E. camaldulensis* and *E. largiflorens* is dissimilar to the declining states. In the workshop (2015) it was found that the *intermediate* state in *Eucalyptus coolabah* and *A. stenophylla* is not well known. Overton *et al.* (2014) presented a simpler recovery pathway for 'shrublands' (i.e. *D. florulenta*) from *critical* to *poor* to *medium* without an *intermediate* state. See Overton *et al.* (2014) for a complete description of the transitions, states and justification of these.

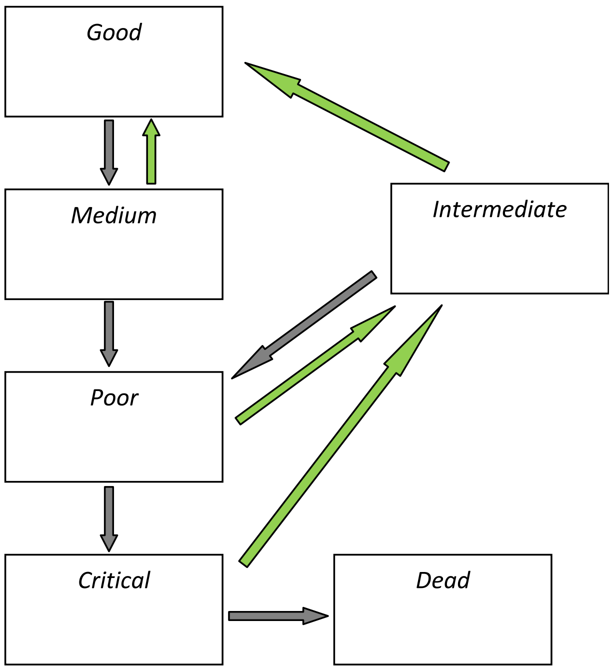

Figure 9. The transitions and condition states for key vegetation species in the Murray-Darling Basin. Black arrows indicate a transition to a less healthy state (primarily as a response to a lack of water), green arrows indicate a recovering transition (primarily as a response to provision of water). After Overton *et al.* (2014).

The summary tables below (Tables 1–8) have been developed based on the information from the Southern Basin given in Overton *et al.* (2014). Where there was information from the Northern Basin it was incorporated into the tables (J. Roberts personal communication). The knowledge-base for *E.*

camaldulensis in the Southern Basin is broad, however, similar knowledge does not exist for *E. camaldulensis, E. largiflorens, Acacia stenophylla* or *Duma florulenta* in the Northern Basin, nor for *E. camaldulensis* subsp. *acuta* or *E. coolabah* subsp. *excerata* anywhere.

These tables describe maintenance of *E. camaldulensis* (forest and woodland)*, E. largiflorens, E. coolabah, Acacia stenophylla* and *Duma florulenta* on the floodplain (Tables 1–6), regeneration of the species on the floodplain (Table 7) and in relation to other life history constraints (population and landscape scale) (Table 8). The key species are all long-lived trees or shrubs, without long-lived soil seed-banks in floodplain habitats. Their decline can occur at the landscape scale, and over a long duration. The length of time for recovery can be longer than the length of time over which the original stress was applied (hysteresis). The description of water requirements given here can differ from previously published estimates in other studies. For example, the generalised water requirements from Roberts and Marston (2011) is that the water regime for maintenance of vigorous growth of *E. camaldulensis* should be flooding 'about every 1–3 years for forests' and 'about every 2–4 years for woodlands'; durations of 'about 5–7 months for forests', and 'about 2–4 months for woodlands'. This recommendation is not erroneous, but is refined here in relation to the condition of the tree (*state*: described in detail in Overton *et al.* (2014)) and provides information about the period of dry time that would cause transition from one state to a different state. These data are based on preference curves (temporal decline in condition in relation to provision or lack of water) for the individual species provided by Overton *et al.* (2014). The model developed by Overton *et al.* (2014) takes into consideration that a tree that has experienced sufficient watering for many years can go without water for a longer time than one that is currently highly stressed. The recommendations provided by previous authors (Wen *et al.* 2009; Rogers and Ralph 2011) are either based on a specific model generated on local flood history data (Yanga National Park for Wen *et al.* 2009), or generalised (with reference to studies by Robertson *et al.* 2001; Bren and Gibbs 1986; George 2004; Bacon *et al.* 1993; White *et al.* 2000), and can be without reference to the condition of the tree, or the duration of dry time it has experienced in the past.

In general floodplain species are adapted to the natural seasonal timing of the unregulated water regime of their habitat for growth and regeneration. Flooding normally occurs in winter-spring and early summer in the Southern Basin. The natural (unregulated) flood regimes in the Southern Basin exhibit a peak following snow-melt in the alps, and the timing of that peak at any one site is related to the distance from the source to the site. Natural flood regimes in the Northern Basin are likely to be later in the year (mid- to late-summer), coincident with peak rainfall events (usually from east-coast lows, cyclones and anti-cyclone rainfall events; Walker Institute 2012). It can be expected that the floodplain vegetation in the Northern Basin is adapted to the later seasonality of flooding and inundation (Workshop 2015).

As with previous assessments of water requirements, and models, these recommendations are largely informed by studies in the Southern Basin, mid- and lower-Murray River, noting however that Northern Basin information was incorporated where available and relevant. This highlights the need for the acquisition of similar knowledge for floodplain vegetation in the Northern Basin.

Table 1. Water regime for the maintenance, decline and recovery in condition ('state') of *E. camaldulensis* subsp. *camaldulensis* (floodplain forest). Flood timing ideally in late Winter to Summer[1]; salinity should be less than 30,000 µS cm^{-1} (Roberts and Marston 2011). Condition descriptions and values (durations) for *E. camaldulensis* floodplain forests are based on those presented by Overton *et al.* (2014), Roberts and Marston (2011) and input from the Workshop (2015). The *Intermediate* state identified by Overton *et al.* (2014) represents a recovering state dissimilar to declining states (*medium, poor* and *critical*), characterised by at least 40% canopy cover largely of epicormic growth and a medium foliage density. The *Intermediate* state can also include mass flowering. *Death* (intuitively) refers to trees without foliage, without sap-flow and without the capacity to respond at all; this was not given as a state in Overton *et al.* (2014). All times and frequencies are estimates set by Overton *et al.* (2014), based on the best available data, for the purposes of modelling states and transitions in floodplain vegetation. Refer to Table 12 for specific references.

State (*sensu* Overton *et al.* 2014)	Description	Flood frequency to maintain state	Dry period to cause decline	Flood frequency to cause recovery to *Good*
Good	Vigorous and healthy; canopy extensive, foliage density high, few dead branches, little to no epicormic growth	1 in 1–2 years[2], duration of 2–8 months[3]	3 years to *Medium;* then 3 years to *Poor;* then 4 years to *Critical*	from *Intermediate*: 2+ in 5 years to return to *Good*
Medium	Not vigorous, canopy extensive, foliage density medium to sparse	1 in 2.5–3 years, duration of 2–8 months	3 years to *Poor;* then 4 years to *Critical*	from *Medium*: 1 year to return to *Good*
Poor	Not healthy, some branches dead, very sparse foliage or leafless	1 in 4–5 years, duration of 2–8 months	3 years from *Intermediate;* 4 years to *Critical;*	from *Poor*: 3+ in 9 years to return to *Intermediate,* followed by by 3+ in 5 years to return to *Good*[4]
Critical	Leafless or with small tufts of epicormic growth, canopy dominated by dead branches and twigs	1 in 10 years, duration of 2–8 months	> 1 years to *Death*; time period dependent on cumulative stresses	from *Critical*: 5+ in 15 years to return to *Intermediate,* followed by 3+ in 5 years to return to *Good*

[1] With additional benefits related to regeneration (see Tables 7 and 12).
[2] Condition maintained with 1 in 2 years floods (Cattelotti *et al.* 2015); previous estimates of 1 in 3 and 1 in 5 are either to maintain in vigorous growth (Roberts and Marston 2011), or relate to one locality (Wen *et al.* 2009) (see Table 12).
[3] Composite estimate based on all references (see Table 7), however Doody *et al.* (2014) found that measures of tree health declined in areas where flooding duration was longer than 60 days.
[4] If flooding in one year is not followed in the next, improvement in condition is not maintained (Ebsworth and Bidwell 2013; 2014; Bidwell and Simoung 2015).

Table 2. Water regime for the maintenance, decline and recovery in condition of *E. camaldulensis* subsp. *camaldulensis* (open woodland). Flood timing should be late Winter to Summer[5]; salinity should be less than 30,000 µS cm-1. Condition descriptions for *E. camaldulensis* floodplain woodlands and the water regimes needed for maintenance, decline and recovery are based on those presented by Overton *et al.* (2014), Roberts and Marston (2011) and input in the Workshop (2015). The *Intermediate* state identified by Overton *et al.* (2014) represents a state dissimilar to declining states, characterised by at least 40% canopy cover largely of epicormic growth and a medium foliage density. The Intermediate state can also include mass flowering. *Death* (intuitively) refers to trees without foliage, without sap-flow and without the capacity to respond at all; this was not given as a state in Overton *et al.* (2014). All times and frequencies are estimates set by Overton *et al.* (2014), based on the best available data, for the purposes of modelling state and transitions in floodplain vegetation. (see footnotes applied to Table 1 for caveats and references).

State (*sensu* Overton *et al.* 2014)	Description	Flood frequency to maintain	Dry period to cause decline	Flood frequency to cause recovery to *Good*
Good	Vigorous and healthy; canopy extensive, foliage density high, few dead branches, little to no epicormic growth	> 5 in 15 years[6], duration of 2–7 months	5 years to *Medium* then 4 years to *Poor* then 4 years to *Critical*	from *Intermediate*: 2+ in 7 years to return to *Good*
Medium	Not vigorous, canopy extensive, foliage density medium to sparse	1 in 4–5 years, duration of 3 months	4 years to *Poor* then 4 years to *Critical*	from *Medium*: 1 year in 1 years to return to *Good*
Poor	Not healthy, some branches dead, very sparse foliage or leafless	1 in 4–7 years, duration of < 2 months	4 years from *Intermediate;* 4 years to *Critical*	from *Poor*: 9 years of > 1 in 3 years to *Intermediate,* followed by > 2 in 7 years to *Good*[7]
Critical	Leafless or with small tufts of epicormic growth, canopy dominated by dead branches and twigs	< 1 in 10 years	> 1 years to *Death*; time period dependent on cumulative stresses	from *Critical*: 15 years of > 1 in 5 years to return to *Intermediate,* followed by > 2 in 7 years to *Good*

[5] With additional benefits related to regeneration (see Tables 7 and 12).

[6] As long as the dry period does not exceed 5 years, 5 wet years in 15 will allow condition to be maintained, this allows for unevenly spaced flood events.

[7] If flooding in one year is not followed in the next, improvement in condition is not maintained (Ebsworth and Bidwell 2013; 2014; Bidwell and Simoung 2015).

Table 3. Water regime for the maintenance, decline and recovery in condition of *Eucalyptus largiflorens*. Flood timing should be late Spring to Summer; salinity tolerance up to 55,000[8] µS cm^{-1}. Condition descriptions for *E. largiflorens* floodplain woodlands and the water regimes are based on those presented by Overton *et al.* (2014) and Roberts and Marston (2011) and from input by participants at the Workshop (2015). The *Intermediate* state identified by Overton *et al.* (2014 represents a state dissimilar to declining states, characterised by at least 40% canopy cover largely of epicormic growth and a medium or greater foliage density, twigs developing into branches. The *Intermediate* state can also include mass flowering. *Death* (intuitively) refers to trees without foliage, without sap-flow and without the capacity to respond at all; this was not given as a state in Overton *et al.* (2014). All times and frequencies are estimates set by Overton *et al.* (2014), based on the best available data, for the purposes of modelling state and transitions in floodplain vegetation.

State (*sensu* Overton *et al.* 2014)	Description	Flood frequency to maintain	Dry period to cause decline	Flood frequency to cause recovery to *Good*
Good	Vigorous and healthy; canopy extensive, foliage density high, few dead branches, little to no epicormic growth	1 in 3–7 years, duration of 3–6 months (av. 55 days $year^{-1}$)[9]	5 years to *Medium* then 5 years to *Poor,* then 4 years to *Critical*	from *Intermediate*: 2+ in 7 years to return to *Good* [10]
Medium	Moderate, not vigorous, canopy extensive, foliage density medium to sparse	< 1 in 7 years, duration of 2 months	5 years to *Poor;* Then 4 years to *Critical*	from *Medium*: 1 in 1 years to return to *Good*
Poor	Not healthy, some branches dead or shed, sparse foliage	< 1 in 10 years, duration of 2 months	4 years from *Intermediate;* 5 years to *Critical;* > 4 years to *Death*	from *Poor*: 10 years of 3+ in 10 years to *Intermediate,* followed by 7 years of 3–5 in 5 years to *Good*
Critical	Leafless or nearly so, with small tufts of epicormic growth, canopy dominated by dead branches and twigs	< 1 in 15 years	> 1 years to death; time period dependent on cumulative stresses	from *Critical*: 18 years of 5+ in 18 years to return to *Intermediate,* followed by 7 years of 3+ in 10 years to *Good*

[8] Doody *et al.* 2009

[9] Monoman Island (Colloff *et al.* 2014)

[10] Positive effects of flooding can last up to 12 years (Slavich *et al.* 2012).

Table 4. Water regime for the maintenance, decline and recovery in condition of *Eucalyptus coolabah* (possibly subsp. *coolabah*). Flood timing should be late Summer[11] (consistent with natural flooding); salinity tolerance is possibly up to 30,000 mg chloride (for populations along the Diamantina River; Payne *et al.* 2006 in Roberts and Marston 2011), groundwater use is likely but has not been quantified. The descriptions of 'state' are based on a combination of the states for *E. camaldulensis* and the input of individuals at the Workshop (2015) (refer to section 10.4 for the sources of information). The data for this table is based on Roberts and Marston (2011) and input of individuals at the Workshop (2015). There is no published description of an *Intermdiate* state for *E. coolabah*, although leaves turn red rather than fall as plants reach the *Poor* state (Workshop 2015).

State	Description	Flood frequency to maintain	Dry period to cause decline	Flood frequency to cause recovery to *Good*
Good	Vigorous and healthy; canopy extensive, foliage density high, few dead branches, little to no epicormic growth	1 in 7–20 years, duration of 9 days[12]– 2 months[13]	Unknown	Unknown
Medium	Not vigorous, canopy extensive, foliage density medium; dead branches	Unknown	Unknown	Unknown
Poor	Not healthy, leaf colour changes to 'red'	Unknown	Unknown	Unknown
Critical	Leafless or with small tufts of epicormic growth, canopy dominated by dead branches and twigs	> 20 years (insufficient data)[14] less if no access to groundwater	Unknown	Unknown

[11] Foster (2015)
[12] Marshall *et al.* (2011)
[13] Foster (2015)
[14] This estimate is not based on empirical data, Foster (2015) estimates distribution of mature trees in areas that flood once every 10–20 years.

Table 5. Water regime for the maintenance, decline and recovery in condition of *Acacia stenophylla*. Flood timing should be Spring to Summer; salinity tolerance is 18,000 mg L^{-1}, groundwater use almost certain, but not quantified. Data for this table are based on that in Roberts and Marston (2011), largely for the Southern Basin, the sources in Table 16 and input of individuals at the Workshop (2015). 'State' has not been described in the literature, so these descriptions are 'best guess'.

State	Description	Flood frequency to maintain	Dry period to cause decline	Flood frequency to cause recovery to *Good*
Good	Vigorous and healthy; canopy extensive, foliage density high, few dead branches	1 in 3–5 years, duration of 2–3 months	> 5 years (insufficient data)[15]	Unknown
Medium	Not vigorous, canopy medium; dead branches	< 1 in 7 years, duration of 2–3 months (insufficient data)[16])	Unknown	Unknown
Poor	Not healthy, dead branches present	Unknown	Unknown	Unknown
Critical	Nearly leafless, canopy dominated by dead branches and twigs	Unknown	Unknown	Unknown

[15] No empirical studies
[16] No empirical studies

Table 6. Water regime for the maintenance, decline and recovery in condition of *Duma florulenta*. Flood timing should be Spring to Summer (in the Southern Basin) or late Summer (in the Northern Basin) (Foster 2015); *D. florulenta* is tolerant of salinity, groundwater use most likely occurs but is not quantified. These condition descriptions and values for *D. florulenta* shrublands and the water regimes needed for maintenance, decline and recovery, are based on those presented by Overton *et al.* (2014), Roberts and Marston (2011) and input from participants at the Workshop (2015). An *Intermediate* state is not factored in, due to insufficient knowledge of recovery from decline. *Death* (intuitively) refers to plants without foliage, without sap-flow and without the capacity to respond from the root-stock; this was not given as a state in Overton *et al.* (2014), but there are some on-going studies concerning this threshold (C. Campbell personal communication). All times and frequencies are estimates set by Overton *et al.* (2014), based on the best available data, for the purposes of modelling states and transitions in floodplain vegetation.

State (*sensu* Overton *et al.* 2014)	Description	Flood frequency to maintain	Dry period to cause decline	Flood frequency to cause recovery
Good	Vigorous with recent growth; leaves may be present; flowering; stems green	1 in 1–1.5 years, duration from 3[17] to 5–8[18], or 6–12[19] months	> 1 years to *Medium;* 7 years to *Poor;* 11 years to *Critical;* >11 years to *Death*	from *Intermediate*: 2+ in 7 years to return to *Good*
Medium	Not vigorous, no leaves, no flowers; stem dull to brown but not brittle	> 1 in 3 years, duration of 3 months	6 years to *Poor;* 10 years to *Critical;* > 10 years to *Death*	from *Medium*: 1 in 1 years to return to *Good*
Poor	Drab, stems brown, dried out and becoming brittle,	> 1 in 8 years, duration of 3 months	4 years to *Critical;* > 4 years to *Death*	from *Poor*: 2 years of > 1 in 2 years to *Medium*
Critical	Stems reduced to brittle twigs, dull brown-grey	< 1 in 11 years, duration of 3 months	< 5 years to *Death*	from *Critical*: 2 years of > 1 in 2 years to *Poor*

[17] MDBA (2006)
[18] Foster (2015) in the Southern Basin
[19] Foster (2015) in the Northern Basin

Table 7. Water regime required for recruitment and regeneration of all species. In some instances rainfall will provide sufficient water for regeneration.

Species	Precondition (flowering stimulus/fruiting stimulus)	Flood timing-regeneration	Follow-up flood (years)	Depth of flood seedling establishment	Flood duration (weeks)
Eucalyptus camaldulensis* subsp. *camaldulensis	Water 24–36 mths prior to seed fall; flowering flood induced in stressed trees; above av. Rain for bud set	Recession Spring/early summer (or sufficient rainfall); artificial watering to extend effect	For lower Murray summer germination-follow-up (or sufficient rainfall)	20–50 cm (soil moisture 10–20%)	4–6 weeks
Eucalyptus camaldulensis* subsp. *acuta	Unknown	Unknown	Unknown	Unknown	Unknown
Eucalyptus largiflorens	Aseasonal flood induced flowering (Aug–Jan, May–Oct): tree condition	Recession spring-summer (or local rainfall) artificial flood not so useful.	Summer after germination (or local rainfall)	4 cm	4 weeks after 2 months of age
Eucalyptus coolabah* subsp. *coolabah	Flowering dependent on tree condition; intermittent rather than annual?	Summer-late summer (but other factors important e.g. rainfall); episodic	Unknown; not required? (c.f. Freudenberger 1998)	Unknown	Unknown
Eucalyptus coolabah* subsp. *excerata	Unknown	Unknown	Unknown	Unknown	Unknown
Acacia stenophylla	Not important	Unknown; seed fall from spring to summer; artificial flood not so useful	Unknown	Unknown	Unknown
Duma florulenta	Flowers in response to rain and flooding	seed fall in response to flood; aseasonal?	9–12 months after germination	<15 cm	3 months

Table 8. **The influence of other factors (population scale or landscape scale) on population sustainability. Salinity has an effect in relation to the ability of species to use groundwater, and use of surface water, and tolerance is given in previous table captions.**

Species	Water Sources	Seed storage/ viability	Grazing, competition and adjacent land use	Salinity	Groundwater extraction	Population constraints/viability
Eucalyptus camaldulensis* subsp. *camaldulensis	Groundwater Lateral bank recharge Rainfall Flooding Ponded surface water	Serotiny in riparian systems (2 yrs). SB present in SW Vic. and SE SA. Dependent on tree condition: release following flood; ant -granivory	modifies ant activity and removal of seed; seedlings directly grazed (more during drought) compete with reeds and weeds	Not generally salinity tolerant	Unknown	insects, birds and bats; seed supply density dependent?/hydrology dependent; little estab. under mature trees Density of stands 100s of years for ecosystem function
Eucalyptus camaldulensis* subsp. *acuta	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Eucalyptus largiflorens	Lack from all sources a constraint	Serotiny in riparian systems (17mths–2 yrs); release uk; no SB; ant -granivory	seedlings are grazed	Salinity tolerant	Big effect: increases reliance on flood and rain	insects, birds and bats;
Eucalyptus coolabah* subsp. *coolabah	Unknown	Potentially (i.e. dormancy can be induced), but not detected	Seedlings are directly grazed; competition from grass not so important (amelioration); regen. is directly cleared	Not generally salinity tolerant	Likely to have big effect, usually floods not required because of groundwater	Clearing of regenerating stands
Eucalyptus coolabah* subsp. *excerata	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Acacia stenophylla	Unknown	Not buried, but dormant	competition from *Salix* occurs	Salinity tolerant	Unknown	seed coat dormancy
Duma florulenta	Unknown	No seed bank; ant -granivory	Unknown	Salinity tolerant	Unknown	Dioecious, heavily reliant on veg. reproduction

9. WATER PLANT FUNCTIONAL GROUPS

9.1 OVERVIEW

- Plants are useful indicators of water regime requirements, as well as other characteristics of ecosystem health.
- Such groupings are currently used in North America (https://plants.usda.gov/core/wetlandSearch USDA) and Europe (European Water Framework Directive) for assessment, comparison, evaluation and management of wetlands and riparian zones.
- The diversity of species, and varied regional distribution of species restricts the use of individual species at the landscape level.
- When species are grouped in relation to their responses (Water Plant Functional Groups) the groups can be used to
    - used to inform ecosystem responses to environmental watering (Reid and Quinn (2004)
    - assess floodplain vegetation resilience (Colloff and Baldwin 2010).
    - communicate about vegetation responses to environmental flows to the general public (Nielsen *et al.* 2013)
    - assess weediness (and weed control) (Stokes *et al.* 2010)
    - distinguish high diversity wetlands with different water requirements (Casanova 2011)
    - allow comparison of wetlands with the same water regimes, but different suites of species (Campbell *et al.* 2014)

However, Australia does not have a uniform, continent-wide approach, or consistent allocation of species to groups, that would allow it to be used throughout the Murray-Darling Basin. In the absence of a consistent approach, researchers who use this protocol tend to 'do their own thing', creating individualised groups that prevent basin-wide comparisons. The Workshop attendees identified the need for a consistent, robust approach and a single list of species in groups to be able to use the concept to the maximum benefit. A preliminary database has been compiled as a result of other processes, e.g. ACEAS working group, The Living Murray (C. Campbell personal communication) and Commonwealth Environmental Water Holder Long Term Intervention Monitoring study. Further resources are required to build on this concept and complete development of a database and delivery in a format suitable for use by policy makers, planners and researchers. Development of this concept will maximize the utility of data that is currently being gathered, and provide a predictive framework for plant responses in relation to environmental flows.

9.2 RATIONALE

Allocation of plant species to groups (taxonomic, functional, morphological, or in relation to origin or life history) that allow recognition of similarity of response to experimental treatments, or observed environmental variation, is a very common tool used by researchers, especially when dealing with large, speciose data-sets (Capon 2008; Eldridge *et al.* 2010; Kirby *et al.* 2013; Johns *et al.* 2015).

Representative, ’iconic’, ’flagship’, ‘indicator’ or ‘umbrella’ species of plants are commonly used in the development of environmental watering targets and surrogates for community response (Rogers *et al.* 2012; Johns *et al.* 2015). Rogers *et al.* (2012) used a dataset of 54 plant species to determine inundation groups on the Murray-Darling Basin floodplain. They found that indicator or ‘iconic’ species (including four of the key species in this report: *Eucalyptus camaldulensis, E. largiflorens E. coolabah* and *Duma florulenta*) described only one third of all the species’ inundation requirements (60% similarity). Johns *et al.* (2015) examined the relative utility of different plant species classification measures, and found significant differences in the amount of variation detected among them. In contrast, the ‘functional group’ approach was found to be useful in understanding plant community responses to disturbance (Noble and Slatyer 1980; Eldridge and Lunt 2010). Additionally, when the classification of functional groups can be based on ecological responses, it has been used to interpret and predict change in community dynamics (Nobel and Gitay 1996; Boulangeat *et al.* 2012; Campbell *et al.* 2014; Casanova 2015), resilience to stress (Colloff and Baldwin 2010), reduce data-set variability (Campbell *et al.* 2014; Johns *et al.* 2015) and communicate ecological responses to the general public (Nielsen *et al.* 2013; Campbell *et al.* 2014). Identification and allocation of species to different groups might enable other processes to be discerned or inferred. For example, if *E. camaldulensis* and *Juncus ingens* have the same water regime requirements (Rogers *et al.* 2012) it might place them in competition for space on the floodplain, so competitive relationships might be able to be determined. Similarly if animal functional responses are included, co-occurrence with plant groups can generate hypotheses about the provision of habitat or resources (Rogers *et al.* 2012).

In the past, functional classifications have been developed for wetland plants: Boutin and Keddy (1993) grouped wetland plants using functional life history characteristics; Keddy *et al.* (1994) used functional groupings in relation to competitive ability in wetland plants. Wetland Indicator Categories (Reed 1997) are widely used in North America. In Australia, this approach was pioneered for wetland plants by Brock and Casanova (1997) who examined plant functional responses to water regimes, specifically in relation to the germination, growth and reproduction of plants in shallow wetlands of the Northern Tablelands of New South Wales. The concept was developed further by Leck and Brock (2000), Casanova and Brock (2000) and Casanova (2011).

In Brock and Casanova’s (1997) initial study, 60 species were classified (after multivariate analysis) in relation to growth form (low-growing, upright or floating), water levels that stimulated germination (damp, fluctuating or underwater), water levels that simulated growth (submerged, emergent or on saturated soil), where reproduction took place (underwater, out of water above flooded soil or out of water above dry soil), and the water depth at which plants typically produced flowers or fruit (dry, saturated soil, shallow or deep water) (Table 9). Although woody vegetation typical of the Murray-Darling Basin was not included in this study, in most subsequent studies the key species (that form the basis of this literature review) were allocated to the ATe (Amphibious Fluctuation-tolerator, Emergent) group of plants (Table 11).

A number of studies have used the groups of Brock and Casanova (1997). Reid and Quinn (2004) used the groups to investigate floodplain wetlands in the Barmah-Millewa forest, and analysed *E. camaldulensis* as a separate category. They found that the use of WPFGs allowed detection of the effects of environmental flooding, and that analyses based on ‘species of management interest’ were not as good at indicating response to inundation as were WPFGs. Colloff and Baldwin (2010) used the groupings to assess floodplain vegetation resilience and response to flooding, and found that functional diversity (and biodiversity resilience) was related to the number of species in each functional group. Eldridge and Lunt (2010) found that the groupings with the addition of whether the species were native or exotic assisted in interpretation of patterns of weediness in Murray-Darling Basin floodplain ecosystems. Stokes *et al.* (2010) used 5 of the 7 groups (not ATl or S: *see* Table 9) to distinguish the differences between exotic and native understory species responding to flooding.

Table 9. Definitions of Water Plant Functional Groups (after Brock and Casanova 1997 and Casanova and Brock 2000).

First level of classification	Second level of classification	Definition
Submerged (S)	n/a	Fully aquatic species that germinate, grow and reproduce under-water
Amphibious (A)	Fluctuation Tolerator – low growing (**ATl**)	Species which germinate in damp or flooded conditions, which tolerate variation in water level, which are low-growing and tolerate complete submersion when water-levels rise.
	Fluctuation Tolerator – emergent (**ATe**)	Species which germinate in damp or flooded conditions, which tolerate variation in water-level, and which grow with their basal portions underwater and reproduce out of water.
	Fluctuation Responder –floating (**ARf**)	Species which germinate in flooded condition, grow in both flooded and damp conditions, reproduce above the surface of the water and which have floating leaves when inundated.
	Fluctuation Responder – plastic (**ARp**)	Species which germinate in flooded conditions, reproduce above the surface of the water, and which have morphological plasticity (e.g. heterophylly) in response to water-level variation.
Terrestrial	Terrestrial damp (**Tda**)	Species which germinate, grow and reproduce on saturated soil.
	Terrestrial dry (**Tdr**)	Species which germinate, grow and reproduce where there is no surface water and the water table is below the soil surface.

They found that species groups differed in the season of survey: there were more exotic Tdr species in winter and spring, and more exotic ATe species in winter and autumn when compared over seasons. In general exotic species were in the Tdr and Tda groups, and native species were in all groups distinguished (Stokes *et al.* 2010).

In a later study, the limitations of grouping woody vegetation (e.g. *E. camaldulensis*) with other species (e.g. *Eleocharis acuta* and other monocotyledons) was recognised, and an additional functional group was delineated (Table 10), specifically for woody vegetation that had serotiny, could access groundwater, and did not contribute to a long-lived soil seed bank (Casanova 2011). An analysis of the vegetation in one of the sub-catchments of the Murray-Darling Basin (Angas River) provided segregation of species-rich sites with an abundance of woody vegetation (e.g. lightly grazed riparian and floodplain sites) from species rich sites with other emergent vegetation (e.g. temporary wetlands near Lake Alexandrina). Under this scheme all the *Eucalyptus* species in this review, and *Acacia stenophylla,* would be classified as Amphibious Fluctuation-tolerator Woody, (ATw) distinct from herbaceous emergent species that form a persistent seed bank in the soil (Table 10).

In a study of 18 wetlands of the lower River Murray (Lindsay-Mulcra-Walpolla Islands and Hattah Lakes), Campbell *et al.* (2014) allocated species into ten functional groups (largely based on Brock and Casanova 1997 and Casanova 2011) and found that it improved interpretation of plant community responses to flooding, and allowed comparison of flooding responses in disparate groups of wetlands (where the taxonomic diversity prevented direct comparison of community responses). Analysis of the wetland flora using different taxonomic levels (species, genus, family) distinguished between inundation history, but there were significant differences among individual wetlands, and between geographical locations, as well. Analysis on the basis of WPFG found that the same wetlands could be distinguished on the basis of inundation history, and reduced the apparent variability among wetlands. Thus the consequences of water regime (in this case, environmental watering) could be compared at a landscape scale, rather than being confounded by differences among individual wetlands, or geographic separation. They suggested that this approach could help to develop benchmarks or measures of ecological response to water regime. Additionally the use of WPFGs can be used to communicate to non-botanical audiences about water plant diversity and response to water regime (Nielsen *et al.* 2013.).

Table 10. Description of the characteristics of plants in each of the Water Plant Functional Groups. These definitions are based on WPFGs developed by Brock and Casanova (1997) with the addition of ATw, Se, Sr and Sk groups.

FunctionalGroup code	Definition
Tdr	Terrestrial dry. This species group does not require flooding and will persist in damper parts of the landscape due to localised high rainfall. Species in this group can invade or persist in riparian zones and the edges of wetlands, but are essentially terrestrial.
Tda	Terrestrial damp. These species germinate and establish on saturated or damp ground, but cannot tolerate flooding in the vegetative state. As such they can persist throughout the environment in dry puddles and drains. They grow on bare ground following flooding or in places where flood-water has spread out over the landscape long enough to saturate the soil profile. They require the soil profile to remain damp for c. 3 months.
ATl	Amphibious fluctuation tolerator – low growing. This species group can germinate either on saturated soil or under water, and grow totally submerged, as long as they are exposed to air by the time they start to flower and set seed. They require shallow flooding for c. 3 months.
ATe	Amphibious fluctuation tolerator – emergent. This species group consists of emergent monocots and dicots that survive in saturated soil or shallow water but require most of their photosynthetic parts to remain above the water (emergent). They tolerate fluctuations in the depth of water, as well as water presence. They need water to be present for c.8–10 months of the year, and the dry time to be in the cooler times of the year.
ATw	Amphibious fluctuation tolerator – woody. This species group consists of woody perennial species that hold their seeds on their branches, require water to be present in the root zone all year round, but will germinate in shallow water or on a drying profile. If they grow on floodplains they require flooding and restoration of the groundwater levels on a regular basis. Intolerant of continuous flooding.
ARp	Amphibious fluctuation responder– plastic. This species group occupies a similar zone to the ATl group, except that they have a morphological response to water level changes such as rapid shoot elongation or a change in leaf type. They can persist on damp and drying ground because of their morphological flexibility but can flower even if the site does not dry out. They occupy a slightly deeper/wet-for-longer site than the ATl group.
ARf	Amphibious fluctuation responder– floating. This group consists of species that grow underwater or float on the surface of the water, or have floating leaves. They require the year-round presence of free water. Many of these can survive and complete their life cycle stranded on the mud, but they reach maximum biomass growing in 'open' water all year round.
Se	Perennial – emergent. This category refers to woody and monocotyledonous species that require permanent water in the root zone, but remain emergent. They thrive where water levels do not fluctuate or fluctuate little (i.e weir pools, dams). Tolerant of continuous flooding.
Sk	Submerged – k-selected. These species require that a site be flooded to >10 cm for at least 6 months for them to either germinate or reach sufficient biomass to start reproducing sexually. Many have asexual reproduction (fragmentation, rhizomes, turions). Completely water dependent, true aquatic species.
Sr	Submerged, r– selected. These species colonise recently flooded areas. Many require drying to stimulate high germination percentages, they frequently complete their life cycle quickly and die off naturally. They persist via a dormant, long-lived bank of seeds or spores in the soil. Their habitats can be flooded from once a year to once a decade, to a depth > 10cm.

9.3 USE IN THE MURRAY-DARLING BASIN

The aim of this section is to determine if the five key floodplain species central to this report in the Murray-Darling Basin can be, or have been, classified into WPFGs and whether the use of WPFGs can assist in identification of their water requirements.

Water Plant Functional Groups (sensu Brock and Casanova 1997) have been widely used in the Murray-Darling Basin to assist in the interpretation of landscape-scale pattern and process. They have been used to describe wetland flora responses to water regime (Casanova 2011; Gehrig *et al.* 2011; Gehrig *et al.* 2012; Nicol *et al.* 2010; Bowen *et al.* 2011; Bidwell and Wills 2015; Bennets and Jolly 2010; Johns *et al.* 2010), and used to segregate species in relation to their requirements for water of different depths and durations (Casanova 2011; Nicol *et al.* 2010; DEWNR 2012). Additionally, WPFG responses have been used in a predictive manner in relation to vegetation distribution (Casanova 2011; Nicol *et al.* 2010). The groups have been useful, to the extent that standardised approaches have been developed in South Australia (Nicol *et al.* 2010) and New South Wales (Bowen 2013). Similarly, they have been used in Murray floodplain forests in Victoria (Bennetts 2014), Linday-Wallpolla, Hattah Lakes and along the Darling Anabranch (C. Campbell personal communication). However, because of a lack of consistent listing and without a framework specific to the Murray-Darling Basin, some workers have tended to 'do their own thing' in relation to groups and group names, stymieing a 'basin-wide' approach.

To date, four of the five key species have been allocated into groups by different authors, but there is a distinct lack of consensus related to the classification (Table 11). Despite this, there has been a reasonable amount of work done on the responses of WPFGs in relation to water regime and flow. In general the *Eucalyptus* species have been classified as Tda, Tdr or ATw, and *Duma florulenta* has been classified as Se, ATw or ARp. This review highlights the need for an analysis of the species and a consistent approach to their classification in relation to water requirements.

The site-specific flow indicators for environmental assets in the Northern MDB have been summarised into five flow bands (Hale *et al.* 2014):

- Cease to flow events
- Low flow conditions (base-flows)
- Within channel flow pulses (i.e. freshes);
- Medium flow pulses that can inundate low levels of the floodplain, anabranches and some billabongs with low level connection and create significant connection between permanent parts of the channel network (bankfull flows); and
- High level flow pulses that inundate substantial portions of the floodplain and terminal wetland areas (overbank flows).

WPFG can be useful for informing flow parameters for water allocation for the five key species in this review, when we know how WPFGs respond to the different flow indicators.

Some groups respond only to low-flow conditions, others occur only as a result of high level flow pulses. A single presence/absence survey can detect these groups and allow prediction of the spatial extent and temporal duration of flow that produced the communities. Understanding the historical extent and duration of flow can provide guidance for the delivery of managed flows, and provide information about the consequences of not delivering flows.

During cease-to-flow or base-flow conditions water is retained only within waterholes and impoundments, providing habitat for Se and Sk species (where they are not affected or removed by herbivory, disturbance or poor water quality). ATe species will also occur at the edges of waterholes and impoundments, and Tdr species can be expected to respond to local rainfall events.

Within-channel flow pulses or 'freshes' can improve water quality in permanent/near permanent habitats for Se and Sr species, and increase habitat availability and germination opportunities for species in the ATl, ATe and Tda groups on the channel slope and on in-channel banks. ATw species on the floodplain benefit from freshening of the groundwater in the riparian zone.

Bank-full flows can inundate low lying floodplain habitats (wetlands and flood-runners) and stimulate germination in most WPFGs (ARp, ARf, ATe, ATl, Sr, Tda) in those places; provide connectivity along the channel for dispersal of seeds and spores; and improve water quality within channels, permanent waterholes and the local groundwater (for ATw species) (Barrett *et al.* 2010).

Overbank flows that inundate the extent of the floodplain and wetlands can facilitate dispersal of many groups, stimulate sexual reproduction, and recruitment, in ATw species, as well as providing all the opportunities that bank-full flows provide. Additionally they can provide space for recruitment through sediment movement, scouring and re-deposition. When flood-waters retreat Tda species are recruited on damp soil and mature ATw species (released from the stress of water-logging) can access raised and freshened groundwater.

9.4 THE NEED FOR A CONSISTENT APPROACH: 'THE ONE TRUE LIST'

The adoption of a consistent approach to the classification of plant species into WPFGs could potentially allow reliable predictions to be made about plant community responses across a landscape (Campbell *et al.* 2014). Without consensus about the placement of the five species in this review, the use of WPFGs is not likely to be comparable or reliable across the basin. At the moment the key species have been allocated to a number of different groups (Table 11).

Table 11. Ways in which the five key species have been classified into functional groups by various authors. None of the five species were referred to in Brock and Casanova (1997), or Casanova and Brock (2000). *Eucalyptus coolabah* has not been classified into a functional group in any study.

Species	*Author and Classification*						
	Murray (2014)	Casanova (2011)	Bice *et al.* (2014)	Reid and Quinn (2004)	Holland *et al.* (2013)	Johns *et al.* (2010)	Kirby *et al.* (2013)
Eucalyptus camaldulensis		ATw	Tree (divided into adult and recruit)	Tda	Amphibious	Tda	
E. largiflorens		ATw				Tdr	
Acacia stenophylla	Stationary persistent	ATw	Tree				
Duma florulenta	Fluctuating persistent	ATe	Amphibious		Amphibious	Amp	ATw

Without a nationally recognised framework of classification there has been a tendency for individual users to

- **use fewer groups** (sometimes using the levels of Terrestrial, Amphibious and Submerged only; sometimes some of the subcategories: Bowen *et al.* 2011; Johns *et al.* 2010),
- **rename categories** (e.g. ATe and ATl described as Atol: Bowen *et al.* 2011; Retention of ATe, but renaming Se 'Emergent': DEWNR 2012; renaming all the Amphibious groups as Amp, and Submerged groups as Aqu: Johns *et al.* 2010)),
- **develop their own groups** (e.g. FP, Nicol *et al.* 2010) or
- **reclassify groups for particular purposes** (e.g. Bidwell and Wills 2015; Bennets and Jolly 2010; who renamed groups with numbers (i.e. PFG1, PFG2) and amalgamated ARf with Sr species because they occupied areas of the same habitat).

Without a 'consensus' and easily accessible database, of all the wetland-dependant species, there can be sometimes different (or erroneous) classification of same species in different studies (Bidwell and Wills 2015 cf. Brock and Casanova 1997).

Although this review of the literature indicates that using WPFGs has potential to assist in the development and understanding of water requirements for vegetation in the Murray-Darling Basin, the lack of a consensus approach is a limitation to their use.

The concept would have most utility if the same groupings were used in all studies; and if there was a more comprehensive listing of species from the Murray-Darling Basin. Development of this concept will maximize the utility of data that is currently being gathered (for TLM and LTIM), and provide a predictive framework for plant responses in relation to environmental flows.

10. COMPREHENSIVE TABLES

The following tables provide citation to the original references. References to information are colour-coded dependent on source: Green is for refereed scientific literature; Red is for compilations, reviews and books; Blue is for published reports, proceedings and theses (grey literature); Purple is for personal communications

10.1 *EUCALYPTUS CAMALDULENSIS* SUBSP. *CAMALDULENSIS*

Table 12. Ecological water requirements for *Eucalyptus camaldulensis*: processes, drivers and stressors.

Regeneration process	Drivers/Stressors
General water requirements	• Can use fresh to moderately saline groundwater, lateral bank recharge from river flow and overbank flooding (Doody *et al.* 2014; Doody *et al.* 2015). Genetic diversity of populations is conserved during extended drought (Dillon *et al.* 2015)
Development of inflorescences (pollen and egg development)	• Yield dependent on water availability 24–36 months prior to seed fall (Jensen *et al.* 2006) • Inflorescences appear in November (Dexter 1978) • Mean seed viability: 6052 viable seeds per 10g (Gunn 2001) • Takes 2 years from initiation to seed fall, concurrent, annual cycles can occur in healthy trees, a single 2-year cycle in stressed trees (Workshop 2015)
Flowering	• Varies geographically (Jensen *et al.* 2006) • Possibly flood induced (Rogers and Ralph 2011) • Occurs late-spring to mid-summer (Dexter 1967) • Intensity is variable and unpredictable (Dexter 1967) • High flowering every second year (Cunningham *et al.* 1981; McDonald *et al.* 2009) • Flowering occurs 9–12 months after bud development (Dexter 1978) 13 months (Colloff 2014) • Peak period is December to February (Boland *et al.* 2006) • For subspecies *camaldulensis* December to January (Clemson 1985; Birtchnell and Gibson 2006; Butcher *et al.* 2009)
Pollination	• By insects, bats and birds (Butcher *et al.* 2009)
Bud/seed development	• Seeds mature about 9 months after flowering (Dexter 1967; Dexter 1978) • May be shed during excessively dry conditions (Jensen *et al.* 2006) • High flowering doesn't imply abundant seed production (Dexter 1978) • Requires watering in Dec-Feb for bud set (Jensen *et al.* 2007; 2008) • Requires average rainfall in autumn to maintain buds and aerial seed bank (Jensen *et al.* 2007; 2008)

Regeneration process	Drivers/Stressors
	• Potential seed supply has been reduced through clearing, river regulation and water extraction (Meeson *et al.* 2002)
Seed fall	• Eucalypts can store seed in the capsules (in canopy: serotiny) for up to 2 years (George 2004) • Varies geographically (Jensen *et al.* 2006) • Varies seasonally (Dexter 1970b) • Possibly flood-induced (George 2004a) • Throughout the year (Pettit and Froend 2011) • Higher in spring (Dexter 1978) • Peaks in spring and autumn (George 2004) • Lowest in winter (Dexter 1978) • About 600,000 seeds per tree (Jacobs 1955) or considerably less (George *et al.* 2005) • Trees in poor condition retain seed longer (George 2004) • Trees in good condition produce more seed (George 2004) • Requires watering at seed fall (Dec-Feb) to stimulate germination and recruitment (Jensen *et al.* 2007; 2008) • Seed predation varies through the year, lowest under sheep grazing, highest in ungrazed, high under cattle grazing (Meeson *et al.* 2002) • Although seed is produced on a 2-year cycle by individual trees, within a community some trees always producing seed (A. Jensen personal communication)
Seed dispersal	• Primary mechanisms are gravity, wind (Turnbull and Doran 1987) and water (hydrochory) (George 2004; Roberts and Marston 2011; Rogers and Ralph 2011) • Most seed falls within a distance of twice the height of the tree (Boomsma 1950; Cromer 2007) • Flooding can carry seed considerably further (Greet *et al.* 2011; Roberts and Marston 2011) • Seeds float for 10 days (Pettit and Froend 2001) • Seeds are concentrated in strand-lines (Jensen 2008) • Excessive flooding can destroy seeds (Rogers and Ralph 2011) • Predation by ants (Pettit and Froend 2001; Meeson *et al.* 2002) and other insects (Jacobs 1955), which can be mitigated by flooding • Predation by ants is increased where cattle grazing is high (Meeson *et al.* 2002) • No evidence of soil seed bank (Roberts and Marston 2011) • Does not form a long-lived soil seed bank (Holland *et al.* 2013) • Held in the canopy for up to 2 years (Jensen *et al.* 2007; Jensen *et al.* 2008)

Regeneration process	Drivers/Stressors
Germination	• Dependent on moist soil conditions (Dexter 1978), warmth, oxygen and light (Turnbull and Doran 1987) • Germination takes about 10 days (Pettit and Froend 2001) • Seeds sink when they germinate (Pettit and Froend 2001) • Not flood dependent – germination can occur following rainfall (Dexter 1978) • Between 11 and 34 °C (not below 8 °C). Optimal temperature c. 33 – 35 °C (Grose and Zimmer 1958); fluctuating temperatures better than constant (Workshop 2015) • Main restraints are low temperature and darkness; germination in dark is 5%, compared to in light 70% (Grose and Zimmer 1958) • Winter floods expose germinants to unfavourably cold conditions (Dexter 1978) • Late summer floods can expose germinants to unfavourably hot conditions (Rogers and Ralph 2011) • Greatest when widespread flooding occurs in spring or early summer (Dexter 1978; Pettit and Froend 2001) • Germination 1.98% at 15 °C, 2.1 % at 20 °C (8hrs dark/16 hrs light) (D.Duval personal communication) • Large numbers in response to natural flood events (c.f. artificial watering) (Holland *et al.* 2013) • 'a thousand or more per m^2' (Colloff 2014) • Takes about 10 days depending on seed condition and salinity of the water (Workshop 2015) • 14 days to visible cotyledons (A. Jensen personal communication)
Seedling establishment and growth	• In moist soil on recession floodwater (Dexter 1967b) • Requires a 'gap' or lack of competition (Workshop 2015) • Susceptible to moisture stress and heat (George 2004a; Jensen *et al.* 2008) • Seeds germinated after 10 days of floating, and die unless they reach moist soil (A. Jensen personal communication) • 'within a year, roots a metre or more down, stem to 4cm' (Colloff 2014) • Susceptible to prolonged flooding (Roberts and Marston 2011) • Develop adventitious roots in response to flooding (Dexter 1978; Heinrich 1990 in Roberts and Marston 2000) • Resilience to flooding increases with size (Dexter 1978) • Grazing of seedlings (cattle, kangaroos, rabbits) is increased during drought (Dexter 1978; Meeson *et al.* 2002) • Sheep readily graze seedlings (M.T.Casanova personal communication)

Regeneration process	Drivers/Stressors
	• Cattle are less likely to graze seedlings (M.T.Casanova personal communication) • Possibly inhibited by frosts (Roberts and Marston 2000) and susceptible to cold (Rogers and Ralph 2011) • Shed leaves to develop roots if conditions are dry (Dexter 1978; Roberts and Marston 2000) • Inhibited by drought conditions (Dexter 1978) • Root-shoot length ratios average about 4.5 (Dexter 1970b; 1978) • Little establishment after artificial watering (Holland *et al.* 2013) • 80,000 $MLday^{-1}$ required for successful recruitment (Lamontagne *et al.* 2012) • Self-thinning of stands removes 40-60% of recruits (George 2004) • Little establishment under canopy of mature trees (Colloff 2014) • Seedlings can be slow to recover from flooding (flooding as a stress) (Argus *et al.* 2015) • Requires watering 1–2 months after spring rain, or 1–2 months after small floods, to support seedlings (Jensen *et al.* 2007; 2008) • 10 – 20 % soil moisture is ideal (A. Jensen personal communication) • Patchy recruitment has to assess the effects of nutrient levels, grazing and ground cover type (Taylor *et al.* 2014). • Needs to establish a 'sinker root' for further growth (A. Jensen personal communication)
Sapling and pole-stage growth	• Stands self-thin (Colloff 2014) • Dependent on suitable conditions (George 2004) • 'six or seven years to 10m tall' (Colloff 2014)
Maturity	• 'flowers and fruit in 7–10 years' (Colloff 2014) • Tree condition affects seed production (George 2004a; George *et al.* 2005) • Least drought tolerant of the floodplain species (Doody *et al.* 2014) • Frequency: Requires inundation once every 3 years (Roberts and Marston 2011) • Frequency: Requires inundation once every 5 years (Wen *et al.* 2009) • Duration: 5–7 months for forests (Young 2011; Wen *et al.* 2009; Roberts and Marston 2011) • Duration: 2–4 months for woodland (Roberts and Marston 2011) • Duration: 2–8 months (Rogers and Ralph 2011) • Season: winter–spring (Rogers and Ralph 2011) • Transpiration rates of 118 mm $year^{-1}$ (Holland *et al.* 2011), but up 303-1882 mm $year^{-1}$

Regeneration process	Drivers/Stressors
	• Bank recharge (from the river) can provide 82% of tree water needs (Holland *et al.* 2011) • Conservative estimate of longevity is 500 years (Colloff 2014) • Mortality rates during the Millenium Drought of mature trees ranged from 0.94–2.22% in Lindsay, Mulcra and Walpolla Islands between 2007–2010 (Henderson 2011) • Can switch reliance from surface water to groundwater if suitable quality (Workshop 2015)
Condition scoring **Tree- and Stand-**	• Less frequent flooding leads to decline in condition (Cunningham *et al.* 2009; Overton and Doody 2009) • Greater than 60 days can cause a decline in tree condition (Doody *et al.* 2014) • Hydrological connectivity important in maintaining adult tree condition during drought (Doody *et al.* 2014) • Leaf area index of 0.5 is a condition threshold (Doody *et al.* 2015) • A flow event produced an improvement in tree condition after the Millennium Drought but improvement appears short-lived and spatially limited, and trees returned to pre-flood condition in some metrics within 2 years (Ebsworth and Bidwell 2013; 2014; Bidwell & Simuong 2015) • Greatest improvement was seen in sites that received a long flood duration (Bowen *et al.* 2011). • Annual rainfall and flood-group (whole of floodplain vs within floodplain) with time (5 y, 5–50 y, >50 y) were influential predictors of health at Gunbower, in Tri-State spatial variability, inundation history and summer temperatures were important, as well as number of days flooded x time (Colloff *et al.* 2015)
Mature tree recovery from drought	• Has the capacity for water regulation by reducing sapwood area and regulating stomatal conductance, increasing root density and increasing water uptake during flooding (Doody *et al.* 2015) • There can be a two-month delay in recovery after flooding (Doody *et al.* 2014) • Health (good condition scores) was maintained when there were floods at least 1 year in 2; persistence thresholds were strongly associated with annual flooding 4 times in 10 years, and recovery strongly associated with flooding more than 7 times in 10 years (Catelotti *et al.* 2015) • There is a lag effect of changed water regimes, because *E. camaldulensis* is so long-lived, and persists in maturity (Bino *et al.* 2015) • Inundation > 5 years in 10 was strongly associated with recovery of mature trees (Catelotti *et al.* 2015)

Regeneration process	Drivers/Stressors
	• Artificial watering can restore health because of bank-recharge and groundwater freshening (Holland *et al.* 2009) • Thinned stands had higher habitat values and carbon sequestration (Horner *et al.* 2010) • Thinning alone is not sufficient to retain community diversity, needs flooding too (Horner *et al.* 2012) • Healthy trees are 3 x more likely to respond to freshening of groundwater and increased level in anabranch creeks than stressed tress, and 30 x more likely to respond than defoliated trees (Souter *et al.* 2014)
Mortality	• Dense stands experienced higher mortality under water stress than sparse stands, thinning could enhance drought tolerance and survival (Horner *et al.* 2009) • Mean growth rate was <2.5 cm in DBH, over 5 years (Taylor *et al.* 2014) • Mortality rate (for 5 Eucalypt species) is being met by recruitment rate, but only in 9/40 sites; and recruitment is patchy (Taylor *et al.* 2014) • Patchiness and self-thinning are natural (A. Jensen personal communication) • It may take centuries for nesting or roosting hollows to develop (Taylor *et al.* 2014).

10.2 *EUCALYPTUS CAMALDULENSIS* SUBSP. *ACUTA*

Table 13: Ecological water requirements for Eucalyptus camaldulensis subsp. acuta: processes, drivers and stressors.

Regeneration process	Drivers/Stressors
	• The distribution of mature trees in the Condamine river catchment is related to distance from and connectivity to the river, rainfall, agricultural landuse, recent and historical groundwater depth, and recent and historical grazing regime (Kath *et al.* 2014). These are possibly subsp. *camaldulensis*, possibly subsp. *acuta*.
Development of inflorescences (pollen and egg development)	
Flowering	• October to November (Butcher *et al.* 2009; McDonald *et al.* 2009)
Pollination	
Bud/seed development	
Seed fall	
Seed dispersal	• Seeds present (possibly this subsp.) in canopy and on ground in the Northern Basin (Capon *et al.* 2012)
Germination	• Two seedlings (possibly of this subsp.) observed after the 2011 flood (Capon *et al.* 2012) • Few seedlings (possibly of this subsp.) recorded (Northern Basin) (Capon and Balcombe 2015)
Seedling establishment and growth	
Sapling and pole-stage growth	
Maturity	
Condition scoring	
Mature tree recovery from drought	

10.3 *EUCALYPTUS LARGIFLORENS*

Table 14: Ecological water requirements for Eucalyptus largiflorens: processes, drivers and stressors.

Regeneration process	Drivers/Stressors
Development of inflorescences (pollen and egg development)	• A two year cycle from bud (1 year) to flower (9 -12 months) to seed release (2 – 3 months after flowering) (Workshop 2015)
Flowering	• Flowers after a flood irrespective of season (Cale 2009) • August to January (Boland *et al.* 1981); May to October (Roberts and Marston 2000) • Can be over an extended period (George 2004; Jensen 2008) • Dependent on tree condition (George 2004) • Seasonality and patterns of flooding might be different in the Northern Basin due to different pattern of rainfall (Workshop 2015) • Stressed trees flower in response to flood, but sufficient, healthy trees flower annually, although flooding might enhance flowering (Workshop 2015)
Pollination	• Insects, bats and birds (Holloway *et al.* 2013)
Bud/seed development	• January to February (Jensen 2009) • Mean seed viability: 4952 viable seeds per 10g (Gunn 2001) • Bud and fruit can be shed when conditions are not optimal (Jensen 2009) • Dependent on tree condition and prior season watering (Jensen *et al.* 2008) • Capsules can take up to five months to form, and are retained on the tree for up to 17 months (George 2004) • Water availability important for seed production (Workshop 2015) • Takes 9 – 12 months to form, then releases seed 2 – 3 months following maturation (Workshop 2015)
Seed fall	• Stored in the canopy for up to 2 years (Jensen *et al.* 2008; Jensen 2009) • Release triggers unknown (Gehrig 2013), might be fire or flooding (Jensen *et al.* 2008) • Peak release is in summer (Jensen *et al.* 2008) • Does not form a long-lived soil seed bank (Holland *et al.* 2013) • Seed remain on tree for 6 – 15 months after flowering (A. Jensen personal communication) • Maximum seed fall occurs 9 – 12 months after flowering (A. Jensen personal communication)
Seed dispersal	• Seeds die if submerged for > 10 days (Jensen 2009) • Seed bank not generally formed (Jensen *et al.* 2008) • Gravity, or hydrochory (Roberts and Marston 2011)

Regeneration process	Drivers/Stressors
Germination	• Episodic (Duncan *et al.* 2007), with low-levels of continuous germination between episodes (A. Jensen personal communication) • Vulnerable to grazing (Duncan *et al.* 2007) • Requires flooding and/or local rainfall (Jensen *et al.* 2008; Jensen 2009) • Requires 15–30 °C (Magann *et al.* 2012) • Optimal temperature fluctuating: Day:Night 25:35 (Vincent 2012) • Temperatures optimal in summer (Gehrig 2013) • Occurs after natural floods (c.f. artificial watering) (Holland *et al.* 2013) • Maybe flood recession (Litter removal) (Vincent 2012) • 36.5% germination after 3 tests, 673 germinants per gram of seeds (Cromer 2007) • Few seedlings recorded (Northern Basin) (Capon and Balcombe 2015) • Germination occurs when seed lands on bare moist soil, will survive with no grazing and follow up water availability (Workshop 2015) • Strandlines created when seeds land on water, and blow to the edge and germinate and take root in moist soil. Strandlines known from 1956 flood in SA riverland (Workshop 2015)
Seedling establishment and growth	• Grow in summer after shedding old leaves and bark (Jensen 2009) • Can modify transpiration rate (Jolly and Walker 1996) • Soil moisture between 10–25 % is critical for survival (Jensen 2009) • Intolerant of drought (Llewelyn *et al.* 2014) but also slower growth when flooded to 5 cm (Heinrich 1990 in Llewelyn *et al.* 2014) • Appears to experience high seedling mortality (Doody and Overton 2012) • Requires 85,000 $MLday^{-1}$ for successful recruitment at lower elevations (Lamontagne *et al.* 2012) • Requires >100,000 $MLday^{-1}$ for successful recruitment at higher elevations (Lamontagne *et al.* 2012)
Sapling and pole-stage growth	• Slow growth rate due to low transpiration rates (Roberts and Marston 2011) • Relative lack of young trees in the Lowbidgee and the high intensity irrigation zones (McGinness *et al.* 2013)
Maturity	• Trees take 20 – 30 years to reach maturity; the 1992 – 3 cohort at Bookpurnong will have first seed maturing in Summer 2015 (Workshop 2015) • Maintenance of mature trees relies on water availability from ANY source, a flood is necessary when there is low

Regeneration process	Drivers/Stressors
	groundwater quality or availability and insufficient rainfall (Workshop 2015) • A flood of 85,000MLd-1 is required to inundate communities on the Chowilla floodplain (Jensen *et al.* 2008) • Can survive on local rainfall (Jensen *et al.* 2008) • Slow growth rate (Doody, Workshop 2015) • Can survive with groundwater (Doody *et al.* 2009b; McGinness *et al.* 2013; Arthur *et al.* 2011) • Benefit from continual watering throughout the year (Llewelyn *et al.* 2014), 80 mm/month produced better condition than other treatments (Llewelyn *et al.* 2014) • Frequency: once every 3–7 years (Roberts and Marston 2011) • Frequency once in 2 – 5 years, duration 2 – 4 months, groundwater > 3.65 m (Johns *et al.* 2009) • Duration: 2–6 months (McGinness *et al.* 2013) • Optimal is 3–6 months (Roberts and Marston 2011) • Uses groundwater at depths of 1.5–2 m (Gehrig 2013) • Tolerant of salinity to 55,000 µScm^{-1}(Doody *et al.* 2009c) • Transpiration rates of 13–72 mm year^{-1} (Holland *et al.* 2011), but up to 11-365 mm year^{-1} • Mortality rate ranged from 0–2.45 % during the Millenium Drought between 2007–2010 in the Lindsay, Mulcra and Wallpola Islands (Henderson 2011) • Where groundwater is abundant, of good quality and easily accessed, flooding frequency is less important for trees (McGinness *et al.* 2013)
Condition scoring	• Crown density and die off (McGinness *et al.* 2013), colour of canopy (bright to dull) (Llewelyn *et al.* 2014) • Decline when flooding frequency falls to 1 in ten years, and no access to groundwater (McGinness *et al.* 2013) • >100,000 MLday^{-1} required to maintain and improve the health of 80% of *E. largiflorens* woodlands (Lamontagne *et al.* 2012) • An average of 55 days inundation per year (over 3 years) was found to be associated with good health at Monoman Island (Colloff *et al.* 2014) • in NSW,Vic & SA, spatial variability, inundation history and summer temperatures were important, as well as long term flood history (Colloff *et al.* 2015) • <32 EC for groundwater salinity and a depth to groundwater of >3.65 m are thresholds for good health (Colloff *et al.* 2015) • Health is maintained when flooded 4–6 months every 4–5 years (Slavich *et al.* 1999) • Both too much and too little flooding results in unhealthy trees (Hardwick and Maguire 2012)

Regeneration process	Drivers/Stressors
	• Condition Index similar to that of *E. camaldulensis* (Henderson *et al.* 2011) • Can be impaired by too much flooding (Shepheard 1992 in Roberts and Marston 2011) • Once every 2–10 years provides significant changes to bird community and diversity, as well as tree and understory condition (McGuinness *et al.* submitted)
Mature tree recovery from drought	• Regional rainfall is a critical factor, as well as flood frequency for tree health (Workshop 2015) • Can recover their canopy area with epicormic growth as long as favourable conditions persist (Doody *et al.* 2014) • Can respond with increased leaf area for up to 10 years following flooding (Overton and Jolly 2004) • Artificial watering can restore health because of bank-recharge and groundwater freshening (Holland *et al.* 2009) • Where groundwater tables have fallen, rainfall is in deficit and flooding occurs <1 in 2 years, trees will be in poor condition and more likely to die (than where this situation doesn't exist) (McGinness *et al.* 2013)

10.4 *EUCALYPTUS COOLABAH* SUBSP. *COOLABAH*

Table 15. Ecological water requirements for Eucalyptus coolabah: processes, drivers and stressors.

Regeneration process	Drivers/Stressors
Development of inflorescences (pollen and egg development)	
Flowering	• Flowering in the Cooper Creek Basin is between late summer and early Winter (Roberts and Marston 2011) • Varies between region and years (Pettit 2002) • Likely to be dependent on tree condition (Roberts and Marston 2011) • Possibly annual if there is sufficient water (Workshop 2015) • After rainfall (Workshop 2015)
Pollination	• Bees and woodland birds (Workshop 2015)
Bud/seed development	• Might be intermittent rather than annual (Roberts and Marston 2011)
Seed fall	• Viable seed is stored in the canopy, and is not long-lived once shed from fruit (Doran and Boland 1984)
Seed dispersal	• Light seeds dispersed by wind and gravity, hydrochory might be important (Pettit 2002) • No formation of seed bank (Pettit 2002) • Not stored in the canopy for long (Workshop 2015)
Germination	• Germination 100% at 15 °C, 90% at 20 °C (8hrs dark/16 hrs light) (D.Duval personal communication); 90 % in test 1 with 1160 germinants per gram of seeds (Cromer 2007) • Optimal germination at 35°C (Doran and Boland 1984) • Optimal temperature fluctuating: Day:Night 15:30 (Vincent 2012) • Seedlings rare but widespread after the 2011 flood in a single germination event (Capon *et al.* 2012) • Floods are more common than recruitment events, so other factors must play a role (Good 2012) • Few seedlings recorded (Northern Basin) (Capon and Balcombe 2015) • Probably wet soils, or shallow flooding in late summer (Foster 2015) • Maybe flood recession (litter removal) (Vincent 2012) • Susceptible to frost (Workshop 2015)
Seedling establishment and growth	• Mixed growth rates (Capon *et al.* 2012) • Seedling density negatively related to length of last flood event (i.e. longer flood, fewer seedlings) (Capon *et al.* 2012) • Extensive regeneration following floods in the 1970s, and regeneration is episodic in response to rare climatic conditions (Good 2012); flood or rain (Workshop 2015)

Regeneration process	Drivers/Stressors
	• Seedling survival more affected by seasonal conditions and herbivory than competition, mild temperatures required in the first few months (<30°C) (Good 2011, Good 2012) • Regular rainfall is required for establishment (but saturated soil following inundation might be adequate) (Good 2012) • Competition restricts seedling growth but not survival (Good 2012; Good *et al.* 2014) • Seedlings died in the summer, but survived in winter (shade or protection required) (Good 2012; Good *et al.* 2014) • Seedlings die from herbivory (Good 2012) • Flood or local inundation is necessary (Freudenberger 1998) • Vulnerable to fire (Workshop 2015)
Sapling and pole-stage growth	• Seedling regeneration can be very dense, and self-thinning occurs (Good 2012) • Vulnerable to fire (Workshop 2015)
Vegetative reproduction	• Coppicing can occur, development of a lignotuber (Workshop 2015)
Maturity	• Coolibah open woodlands on the Balonne have at least 50% of their total area wetted when 45,000MLday^{-1} is recorded at St George (return interval is c. 3years), at 60,000 (c. 3.6 yrs) the majority of the floodplain is full (Cullen *et al.* 2003). • Patches consist of single aged stands, self-thinning occurs (Good 2012). • Multiple communities exist on the floodplain, their position is indicative of flood level required (Workshop 2015) • Distribution patterns suggest a flood frequency of one in 10 to one in 20 years, duration likely to be several weeks (Foster 2015) • Historical flood duration is 9 days (Marshall *et al.* 2011) • Vulnerable to fire (Workshop 2015)
Condition scoring	• Clearing, weed invasion and livestock grazing threaten the community (Good 2012) • Surface flooding not required to maintain vigour (possibly for 10–20 years), as mature trees can access groundwater (Roberts and Marston 2011) • Dry conditions lead to change in leaf pigments (reddening). Canopy structure is maintained until the tree is close to death (Workshop 2015)
Mature tree recovery from drought	

10.5 *ACACIA STENOPHYLLA*

Table 16. Ecological water requirements for Acacia stenophylla: processes, drivers and stressors.

Regeneration process	Regeneration process
Development of inflorescences (pollen and egg development)	
Flowering	• Spring – Summer (Workshop 2015)
Pollination	• Bees and other insects (Workshop 2105)
Bud/seed development	• No differences in seed abundance in relation to flood frequency or duration (Murray 2014) • Mature in spring to early summer (Murray 2014)
Seed fall	• Does not form a long-lived soil seed bank (Holland *et al.* 2013)
Seed dispersal	• Floating seeds, spread during floods (NSWGI&I)
Germination	• Germination after nicking the seed coat with scapel: 1.1% at 20 °C, 2.1% at 25 °C (8hrs dark/16 hrs light) (D.Duval personal communication); • Nick seed coat, surface sterilise, after ripening (2 months) 77 % (Sahito *et al.* 2013) • C. 80% germination after treating with hot water (M.Henderson personal communication) • Germination of one individual from the seed bank under damp conditions (M.Casanova personal communication) • Occurs after natural flooding (c.f. artificial watering) (Holland *et al.* 2013) • Seedlings relatively common after 2011 flood in a single germination event (Capon *et al.* 2012) • Seedlings abundant and widespread (Capon and Balcombe 2015) • Colonises cleared areas when water returns (Workshop 2015)
Seedling establishment and growth	• Relatively hardy once established? (Doody and Overton 2012) • Can grow rapidly (Capon *et al.* 2012) • Seedling density negatively related to time since inundation (i.e. greater time, fewer seedlings), and positively related to duration of last flood event (i.e. longer flood, more seedlings) (Capon *et al.* 2012) • Roots and shoot growth declines with increasing salinity (from 0.6–16.67 dSm^{-1} (Sahito *et al.* 2013)
Sapling and pole-stage growth	• Salt tolerance conferred by an increase in proteins, sugars, proline and secondary metabolites like phenols, a larger K/Na ratio (Sahito *et al.* 2013)

Regeneration process	Regeneration process
vegetative reproduction	• Suckers freely (NSWGI&I)
maturity	• Transpiration rates of 2–75 mm $year^{-1}$ (Holland *et al.* 2011)
Condition scoring	• Plant height, crown diameter, stem diameter greatest in high flood frequency, high duration zones (Murray 2014), but leaf character don't vary much. • Growth (including symbiosis development) of some Acacias is reduced by *E. camaldulensis* litter (Soumare *et al.* 2013) • API of aerial photography (Workshop 2015) • Canopy density and % dead (Workshop 2015)
Mature tree recovery from drought	• Differences in size and vigour were detected in relation to drought (best is high frequency, long duration, but was averaged over dead trees, and there were more of them in drier sites) (Murray *et al.* 2012) • More dead trees in low flood frequency, short duration zones (Murray 2014) • High tolerance for flooding, low tolerance of drought (Murray 2014)

10.6 *DUMA FLORULENTA*

Table 17. Ecological water requirements for *Duma florulenta*: processes, drivers and stressors.

Regeneration process	Drivers/Stressors
Development of inflorescences (pollen and egg development)	• Dioecious, genders segregated in relation to water regime, male plants found in drier locations (Hardwick and Maguire 2012)
Flowering	• Potentially in response to rain (Roberts 2001) • Higher with long frequency, short duration (Murray 2014) • Flowered very strongly after heavy spring rain (2005) (A. Jensen personal communication)
Pollination	• Dioecious: possibly wind? Bees?
Bud/seed development	• Produces seed readily (Hardwick and Maguire 2012) • No difference among germination from plants subjected to different frequency and duration of flooding (Murray 2014) • Developed seed in 3 – 4 weeks (A. Jensen personal communication)
Seed fall	• Does not form a long-lived soil seed bank (Holland *et al.* 2013) • Seeds shed into the water remain buoyant for 5–25 days (Hardwick and Maguire 2012) • Large numbers of buoyant achenes with hydrochory (Capon *et al.* 2009) • Dropped all seed in 1 – 2 weeks (A. Jensen personal communication)
Seed dispersal	• Buoyant and dispersed by floodwaters (Chong and Walker 2005)
Germination	• Germination 95% under fluctuating temperatures 35/20 °C, (8 hours light/16 hours dark) (D.Duval personal communication) • Occurs after natural flood events (c.f. artificial watering) (Holland *et al.* 2013) • Appears to recruit continuously in the Northern Basin habitats (Capon *et al.* 2012) • Season appears to be critical for germination (late summer to autumn) (Foster 2015) • Few seedlings recorded (Northern Basin) (Capon and Balcombe 2015) • Within 14 days after dispersal (Hardwick and Maguire 2012) • Most germination occurred between 6–12 days of experiment (Murray 2014) • Highest from plants from long duration, low frequency sites (Murray 2014) • Fresh seeds germinate readily in damp soil and whilst floating (Capon *et al.* 2009) • Seeds germinated in water, floating, still alive/growing after 48 days (A. Jensen personal communication)

Regeneration process	Drivers/Stressors
Seedling establishment and growth	• More tolerant of drying than flooding (Capon *et al.* 2009) • 70,000 ML day^{-1} required to stimulate recruitment (Lamontagne *et al.* 2012) • Needs flood once in 12–18 months, of 5–15 cm for 4–6 weeks in late spring/summer (Roberts and Marston 2011) • Opportunistic and rapid under experimental conditions (Holloway *et al.* 2013) • Highly tolerant of both flooding and drying (Capon *et al.* 2009) • Flooding slows growth and delays development (Capon *et al.* 2009) • Drying produces a plastic response in relation to leaf area and leaf production (Capon *et al.* 2009) • Soil type had little effect on responses to flooding or drought (Capon *et al.* 2009) • Establishment of seedlings greater in drier areas (Capon *et al.* 2009) • 10 seedlings found after a watering trial at Chowilla, monitored for 12 months, never > 10 cm as heavily grazed by kangaroos. Individuals with <19 shoots (A. Jensen personal communication) • Seed that fell on dry soil was eaten by ants (A. Jensen personal communication) • Seedlings at higher elevations enter dormancy in dry summer months, consisting of single stalks. They revive with rain or artificial watering (A. Jensen personal communication)
Vegetative growth	• Vegetative spread via arching stems, layering (Jensen 2006) • Rhizomes and stolons, stem fragmentation (Roberts and Marston 2011); possibly tubers (Workshop 2015) • Important in areas of long duration inundation because seedling survival is limited in these places (Murray 2014) • Spreads predominantly via vegetative growth, particularly in more frequently flooded areas (Capon *et al.* 2009) • More important in frequently flooded areas (Capon *et al.* 2009) • Vegetative clones can grow from nodes on stems or roots (A. Jensen personal communication) • Vegetative reproduction occurs only after flood, not rain, arching branches sprouted roots underwater, then lowered onto moist soil on flood recession (A. Jensen personal communication)
maturity	• 70,000–80,000 MLday^{-1} required to maintain or improve the health of 50–80 % of shrublands (Lamontagne *et al.* 2012) • A flood frequency of once in every 2–8 years (but varies geographically). Duration 3–5 months (S) and 6–12 months (N) (Foster 2015)

Regeneration process	Drivers/Stressors
	• Avoid continuous flooding and complete drying is required between floods (Foster 2015) • Natural flooding was spring-summer (S) and late summer (N) (Foster 2105) • Density of stands varies, where it is very thick it is called "bull lignum" (Hardwick and Maguire 2012) • Requires flooding on average once every 5 years, for up to 7 months to maintain condition (Hardwick and Maguire 2012)
Condition scoring	• Enhanced by widespread flooding, appeared dead in 2008, improved in 2011 (Doody and Overton 2012) • Endure drought through a persistent root-stock, up to 3m deep (Craig *et al.* 1991) • Dormant in response to drought (Roberts and Marston 2011) • Lignum Condition Index (Henderson *et al.* 2011) • Although populations respond to rainfall, along the Murray rainfall alone is not sufficient for maintenance in good condition (Henderson *et al.* 2011) • Deciduous in response to drought (Sainty and Jacobs 2003) • Condition varies in response to flood frequency and duration (high frequency (not quantified), short duration (2 months) best) (Murray 2014)
Mature shrub recovery from drought	• Duration of flooding is important in condition recovery (Bowen *et al.* 2011). • Plant regenerate within two weeks following flooding (Craig *et al.* 1991) • Persists sparsely on previously natural floodrunners and in other places with lower flooding frequencies than *E. camaldulensis* communities (Hardwick and Maguire 2012) • One flood, minimum of 3 months, with a maximum 8-year inter-flood period required for sustainable regeneration (MDBC 2006) • High tolerance for both flood and drought (Murray 2014)

11. KNOWLEDGE GAPS

There are obvious gaps in the current knowledge illustrated by the annotations in Tables 2–8. Information is particularly lacking for *E. camaldulensis* subsp. *acuta* that occurs in the Northern Basin, and all subspecies of *E. coolabah.* The knowledge base is improving for *E. largiflorens, Acacia stenophylla* and *Duma florulenta,* although demographic processes, thresholds and controls are not well known. More basic research on the reproductive processes and timing in relation to water regime is required.

Information is accumulating for *E. camaldulensis* subsp. *camaldulensis*, so that we are starting to be able to generalise the responses and tolerances of that species in the Southern Basin. The estimates of flood frequency are likely to be most reliable in the Southern Basin, but their applicability to populations of the same subspecies, and other subspecies in the Northern Basin is not yet known. Although we know that timing of floods for *E. camaldulensis* in the Southern Basin is best in the Winter-Spring, the best timing of flooding in the Northern Basin has not been assessed and could easily be later (i.e. Summer).

The knowledge gaps in Tables 2–6 relate mainly to water regime. In particular there is uncertainty regarding duration of flooding for most species. The data gathered for flow duration is often at the landscape level, and while this will provide response models that are applicable at the landscape level, determination of variability in responses within a community is a consequence of individual tree condition and position on the floodplain. Essentially it is a multidimensional response (tree age, stage, condition, position, distance to groundwater, response to antecedent rainfall, distance to channel, elevation etc.), when the approaches to measurement are necessarily made in fewer dimensions.

The monitoring and remote sensing data that has been collected for these species as part of Commonwealth and State research projects, since the Millennium Drought and subsequent floods, will provide the basis for further investigation, including demographic tracking of individuals over time (for all species listed in this report). We still don't know how long individuals of any of these species can live, or have lived. We can hypothesise that they are K-selected (Macarthur and Wilson 1967), stress-tolerators (Grime 1977), that have high juvenile mortality, in common with many tree and shrub species, and the creation of significant, multiple, long-term monitoring sites (far longer-term than a funding-cycle, even longer than a human research career) would assist with understanding the ecology of these species for better management.

It is likely that the ecology of *Acacia stenophylla* and its role in nitrogen cycling in riparian systems (Brockwell et al. 2005) can be understood in a shorter time than the other key species in this review, since many *Acacia* species are typically short-lived (c. 10–20 years), although there is an estimate of 50 years for *A. stenophylla*.

The Northern Basin Review (Hale *et al.* 2014) identified the following knowledge gaps, and although the situation has not changed significantly, it is likely that projects that are currently in progress will fill some of these gaps.

- Knowledge of the spatial distribution of key plant species, vegetation communities and vegscapes (i.e. vegetation maps). Although a range of vegetation mapping is available across the Northern Basin Scientific Review indicator sites and the Northern Basin generally, consistent vegetation maps (especially across the States' border) are lacking.

- Understanding of spatial variation in the character and condition of key plant species and vegetation communities across the Northern Basin. Knowledge of these is very patchy and inconsistent overall and especially lacking for the Barwon-Darling.
- Understanding of historic variation in the character and condition of key plant species and vegetation communities (i.e. temporal variability). Very little information about historic variability of riparian, floodplain and wetland vegetation is available with the exception of some limited analyses of vegetation productivity (NDVI) and regeneration responses in the Lower Balonne (e.g. Good 2012).
- Species responses to flow. A robust knowledge is lacking for key species in the Northern Basin, particularly in relation to if and how they differ from the same species occurring in the Southern Basin. Information concerning *E. coolabah* is particularly lacking.
- Vegetation community level responses to flow. Knowledge of the water requirements of the understory of asset vegetation is particularly poor.
- Vegscape responses to flow. Responses and variability in responses is poorly known, with the exception of limited analyses of vegetation productivity and regeneration responses in the Lower Balonne (Good 2012)

There are also significant ‘unknowns’ concerning the roles of competition and herbivory in structuring these plant communities. Since un-grazed sites are rare in the Northern Basin (and relatively recently created in the Southern Basin), the impact of grazing and its multitudinous, interacting consequences (see Casanova 2006 for a review) is unknown. The role of grazing in relation to life history stage and tree condition requires further research (Reardon-Smith 2011). The role of fire in structuring these plant communities is not well-known, and the role of weeds and litter accumulation or removal in demographic processes and nutrient cycling is a significant knowledge gap (Good 2012). The risk here is that if water is provided, because of some of these other stressors, the regeneration of species or improvement in condition that is expected, might not occur.

Given the significant diversity of species throughout the Murray-Darling Basin, the climatic variation within the regions, and elevation differences within each sub-catchment, it is not likely that the ecological processes and requirements of all species, or even all species of interest, will be able to be discovered in the near- or medium-term. There is a body of research supporting the use of species groups, rather than diversity indices or ‘key’ species in riparian vegetation management (see section 9), but this is hindered at the moment by a lack of consistency and application of the methodology throughout the basin. The use of WPFGs in the Murray-Darling Basin is likely to enhance prediction, management and communication of outcomes of watering to the general public if these limitations can be overcome.

This review recommends that:

- Long-term monitoring be continued and enhanced, so that demographic processes and ecological responses and thresholds can be determined for the species of interest in the Northern Basin
- The data that have been collected to-date, following the Millennium Drought and flooding events, on flood extent, duration and depth, tree response and condition, and ecological responses of the vegetation, be used as far as possible to understand the stress and recovery pathways for the key species. Initiatives such as that presented by Overton *et al.* (2014) are likely to make a significant contribution to our understanding, but these are (once

again) limited by a lack of information about the ecology of key species in the Northern Basin.

- The utility of WPFGs be investigated for prediction of responses and management of vegetation in the Murray-Darling Basin.

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APPENDIX A: WORKSHOP ATTENDEES AND SUMMARY

Table 18. Attendees at the Floodplain Vegetation Water Requirements Workshop, Mantra Hotel, Brisbane, 16–17 July 2015.

Name	
Michelle Casanova	Private consultant, project contractor
Kelly Marsland	MDBA, project leader
Kerri Muller	Private consultant, facilitator
Workshop contributors	
Sjaan Bidwell	GHD
Sharon Bowen	NSW OEH
Don Butler	QLD DISTI
Cherie Campbell	MDFRC
Sam Capon	Griffith University
Shaun Cunningham	Deakin University
Tanya Doody	CSIRO
Patrick Driver	NSW DPI
Susan Gehrig	SARDI
Mark Henderson	MDFRC
Anne Jensen	Private consultant
Jason Nicol	SARDI
Andrea Prior	QLD NNRM
Jane Roberts	Private consultant
Bill Senior	QLD DISTI
Rachael Thomas	NSW OEH

NOTES FROM MICHELLE CASANOVA

- The majority of discussion on the first day revolved around the water requirements of *E. camaldulensis*, particularly in relation to the life history diagram provided and the summary tables of water requirements. On the second day we dealt with the other species, the model presented by Jane Roberts and Water Plant Functional Groups.
- Northern Basin: An introduction from Sam Capon provided a background about conditions in the northern NSW and Queensland regions of the Northern Basin. Although there was a lot of discussion about the 'Northern Basin' much of it was focused on the border region and rivers, rather than the Gwydir or Macquarie rivers, although those are also in the Northern Basin in the strict sense. It is worth highlighting that where the requirements of floodplain vegetation in the Macquarie and Gwydir valleys have been studied, they are similar to the overall results found in the Southern Basin. The Northern Basin is characterised by a
    - dominance of summer rainfall,
    - higher variability in rainfall annually and over longer periods,
    - higher temperatures overall,
    - less impact of salinity (i.e. groundwater is fresher, rather than the freshwater lenses over saline groundwater that develops in the Southern Basin),
    - different soils,
    - a difference in the development of storages (fewer upper-catchment dams; more floodplain 'harvesting' of water by individual properties)
    - less control of water allocation or delivery, more emphasis on diversion limits
    - different tree species coming in (Coolibah starting to dominate, Black Box less important, different subspecies of *E. camaldulensis* occurring)'
    - possibly more opportunistic responses from the vegetation, rather than strictly seasonal.
- Condition of Floodplain Vegetation: A newcomer to the field of floodplain vegetation might think that condition has been well-defined (from the large number of publications that refer to it), and that methods and understanding of condition-scoring are also well developed (from the large number of monitoring programs that exist). However, the time spent in this workshop discussing the definitions of different 'condition' and the parameters that indicate those 'conditions' suggests that this field is one of active research and discussion. It is apparent that the capacity of vegetation to survive can be dependent on the region (bioregional maxima exist), and the thresholds and requirements for recovery can vary depending on region and precedent conditions (and the species' or individual plant's capacity to be conditioned to those). The small-scale variation in the capacity of individual trees to tolerate stress, between sites and across the floodplain can also be significant. There was agreement that 'condition' should be a measure of the capacity to remain in a particular 'state', but descriptors of those states (e.g. good, medium, bad, critical, sufficient, insufficient) were still under discussion. Some of the best measures (e.g sapwood area) are not easy to undertake in the field, and the current protocols that have been developed (that include e.g. canopy extent and leaf-area-index) are useful and relatively quick to measure. This coincides with the purpose of the inclusion of vegetation in assessment and monitoring, since we need to be able to undertake condition assessment to have these elements considered as targets for water delivery. 'Condition' was a point of discussion because of the

inclusion of recovery from different conditions in the tables of water requirements. See also Jane Robert's contribution below. Information about the recovery potential of vegetation is a critical need for the Northern Basin, since the threat to ecological integrity concerns removal of water, rather than delivery of stored water.

- Summary Tables: There was some discussion about modification of the design of the summary tables of water requirements. It was suggested that access to groundwater and salinity of that groundwater be included for some species. It was considered important to introduce the concept of variability, of antecedent conditions, of 'shades of grey' rather than 'black-and-white' recommendations, but workshop participants did not succeed in developing a consensus format.
- Reproduction: The occurrence of sexual reproduction in floodplain vegetation was also discussed, with reference to the timing, and length of time that was required from bud-set to seed-fall. It was noted that the capacity and stimulus to flower was not necessarily an indicator of good condition, but that trees will sometimes be stimulated to reproduce as a last-ditch effort when about to die.
- Artificial vs natural flooding: the statement in the review, (that natural flooding produces different outcomes from artificial flooding) generated some discussion, particularly in relation to its validity, and how it could occur. It was generally agreed that most effects would be a consequence of the volume and extent of flooding under the two provisions, although the potential for nutrients and microbial activity, flushing of salts and more extensive groundwater recharge were also discussed. The capacity for E. camaldulensis to rapidly develop roots in appropriate depths, and to redistribute water through its root system (via passive diffusion) was mentioned.
- State and transition model: Jane Roberts presented a model of persistence of floodplain vegetation developed by the CSIRO (Overton *et al.* 2014) that provides for condition (different states) and recovery or stress (transitions) from one condition to another for the different elements of floodplain flora. Both insufficient and excess water can be a stress for floodplain vegetation. In the model states are described and each transition from one state to another is quantified. The existence of hysteresis and accounting for precedent conditions were valuable concepts included in this model. The model (having to be used and coded) did not incorporate all growth stages, or reproduction, and rainfall is not included as a source of water for transition from one state to another. See Overton *et al.* (2014) for a complete description of the model.
- Individual species (other than *E. camaldulensis*):
  - Lignum (*Duma florulenta*): germination is usually opportunistic rather than seasonal, and also responsive to rainfall. The duration of wetting is important, especially where lignum forms a structural component of the vegetation (it also exists sparsely as understory in places). The life history diagram should be amended to include (emphasise) the importance of vegetative reproduction and dispersal of vegetative parts. Follow-up flooding can be important for establishment, especially in areas with salinity. Access to groundwater can affect establishment success. There can be segregation of genders in relation to proximity to water. Grazing could impact on establishment.
  - Cooba (*Acacia stenophylla*): This species is opportunistic in its use of water (groundwater, floodwater, rainfall) and can exist with a very low transpiration rate.

In the Northern Basin there appears to be specific timing for life history events. The species is both drought and flood tolerant, and occupies an intermediate space on the floodplain. Its occurrence might be ‘space-limited’ and its role as a nitrogen-fixer is unknown. It could possibly create ‘islands of soil fertility’.

- Black Box (*E. largiflorens*): The life history of *E. largiflorens* is similar to that of *E. camaldulensis* in that the stimulus to phonological events is largely seasonal rather than episodic or opportunistic. There appears to be always some seed in the landscape. It seems that communities can go for >50 years without recruitment of a cohort, but the bottom-line is that recruitment to the population has to be equal to deaths or the population will decline. The presence of mature *E. largiflorens* on the floodplain can be a vestige of previous conditions, and in some places there might have been recruitment of *E. largiflorens* in response to water regulation. Grazing pressure could be important in *E. largiflorens* recruitment, independent of flooding. The species does occur in the Northern Basin, largely on the edges of the floodplain, in the Narran area, and along the Barwon it can be a dominant riparian tree (replaced by Coolibah in the northern valleys). There is data about phenology held, but not yet published, by some researchers.
- Coolibah (*E. coolabah*): subspecies are not generally distinguished, and since there is evidence of hybridization, it might be difficult to undertake in field studies. The species occurs in three different communities, associated with *E. largiflorens*, *Acacia stenophylla* and *Duma florulenta*, as well as on its own. Flooding can assist in establishment, but also cause mortality, and fire might be more important as a cause of mortality for this species than for others on the list. Grazing is probably important, and there are places where there is mass germination, that is not followed by establishment of mature trees. Size at maturity is variable since it can develop a lignotuber and survive coppicing. Flooding might also stimulate development of lignotubers. The presence of a lignotuber allows discrimination between seedlings and suckers. Death is difficult to predict, the drought threshold is possibly higher and return to good condition might take longer. The tree does not drop leaves until it is almost dead, instead they withdraw or deposit pigments (turning red) as a stress response. This change can be detected using remote sensing as well as on ground. Water relations are not well known, and how the subspecies differ in response to flooding is not known. Some of these knowledge gaps are currently being addressed in DSITI.

NOTES FROM DR. KERRI MULLER

Northern Basin Floodplain Vegetation Water Requirements Workshop

Brisbane, 16-17 July 2015

General discussion notes.

Key differences between the northern and Southern Basin

- dominated by summer rainfall
- high temperatures all year round
- greater variability but less time between inundation events

- temperatures are likely to increase under climate change
- less saline areas than Southern Basin
- space for germination is an important factor - bare areas in north are likely to be dry/irregularly watered rather than too salty to support germination (as may be case in the south)
- relatively low water resources development impact in some parts of Northern Basin
- some regulation of flows from in-stream dams but otherwise ‘unregulated’
- floodplain harvesting is major impact in some catchments
- unable to deliver e-water in unregulated areas therefore major management lever is to leave water in the system for the environment (i.e. limit water take and/or diversion)
- different species/subspecies and distribution patterns of floodplain plants although some overlap
- less forest, more woodland (in general) than the south
- forest structure is driven by big events (floods and droughts)
- less “majestic” big gums and more ‘skinny’ trees
- greater areas of lignum shrublands that are important for birds
- two types of lignum shrublands based on low or high flood frequencies
- higher dependence on colonisation from seedbank after floods rather than vegetative expansion in intermittent areas with low emergent vegetation cover
- facilitation could be more important for vegetation diversity (fertility islands)
- concerns in the north regarding woody thickening/encroachment (caused by changes in flow
- there are more cracking clays in the north–this influences vegetation community structure
- timing of flowering for key trees species in the north is largely unknown but may be more opportunistic rather than seasonal.

Roles of water in vegetation health and shaping communities

- tree condition (*state*) can trend either up or down at any stage of the life cycle (a la Jane Roberts’ model)
- returning from ‘poor’ to ‘good’ is likely to take more effort than ‘average’ to ‘good’
- sequences of watering events are important and watering history may override effects of a given watering event especially if plants are in poor condition for years
- floods don’t just lead to growth but are also important for ‘killing plants’ e.g. reducing woody thickening by Acacia/Eremophila (prevent terrestrialisation?)
- lignum can look dead and then recover but there is some evidence from MDFRC that once it looks dead for 5-6 years it really is dead–would be useful to develop a method for determining when a lignum bush that looks dead is really dead (sapwood coring?)
- interspecies relationships are very important e.g. facilitation by lignum
- plant condition is one factor but functional ‘health’ may be different i.e. lignum persistence in the landscape vs. provision of waterbreeding services
- opportunistic germination means that plants may colonise areas that will not provide their water needs e.g. 1956 black box ‘seedlings’ in stasis at Chowilla
- seed set is likely to be strongly affected by drought therefore ‘seed rain’ may not be possible after floods if it has been many years since the last flood
- seed is mostly held on the canopy but there is always a little bit in the soil (A Jensen’s thesis)
- takes approx. 2 years from flowering to seed set

- all the plants require moist soil for germination which is likely to be dependent on surface flows although heavy rainfall may be sufficient depending on soil type
- the presence or absence of lignotubers is likely to be key factor in survival and recovery capacity
- evidence used for determining environmental water needs must show where/when it has come from but it is likely to vary greatly with time and space
- it is unlikely that there will be one set of environmental water requirements for all red gums

Note: land management interactions are also important (grazing, cropping leads to thick/dense seedlings, total grazing pressure is likely to be driven by palatability of different species)

Considerations for using the literature review:

- the summaries of information are mostly based on evidence from the Southern Basin and therefore should be used as hypotheses for application in the north
- use of tree condition terms is important for applying the information in the review document but the descriptions of each category need to be robust and are likely to differ across areas (e.g. need local condition/threshold descriptors)
- the factors that are most likely to differ between the south and different local areas in the north need to be identified and investigated to improve knowledge over time (e.g. rainfall timing, groundwater access, flowering timing, antecedent conditions, water/salt stress, soil types)
- contributions of different water sources are likely to be different in the north from the south e.g. rainfall, surface water, groundwater
- vegetation health is used as a surrogate for water-dependent ecosystem health in the south (due to reliance on surface flows for tree health in saline groundwater areas) but this may not be case in the north where trees are able to maintain their health on fresh groundwater that other flora and fauna cannot access
- development of transition points between tree condition states may be a useful way of packaging complex scientific knowledge for water management
- the watering requirements for different tree conditions could be used in the development of eco-hydrological models and risk assessments but this will require development of 'simple' thresholds between states that alert managers that intervention may be required
- maintaining the review as a 'living document' will ensure that the conceptual framework is developed and updated as new information is available