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# *Washingtonia robusta* (Mexican Fan Palm) as a coloniser in an artificial wetland at Albury, New South Wales

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***Abstract***: *Washingtonia robusta* (Mexican Fan palm) is endemic to the semi-arid zone of California and northern Mexico. Dispersed globally by the horticultural trade, the species has demonstrated its ability to successfully invade disturbed areas and urban landscapes in warm temperate climates. Once established, the plant is extremely hardy. This paper presents the first documented instance of the successful establishment and growth of *Washingtonia robusta* in a pond in continually flooded wetlands at Albury, the first record of it naturalising in New South Wales.

**Keywords:** Weeds in wetlands—*Washingtonia robusta*—*Phoenix canariensis*—frugivory—dispersal of exotic palms—adaptation

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## Introduction

Numerous plants have shown to be adaptable to changing and novel environmental conditions. Many of the exotics have become invasive at the expense of local vegetation. Birds in particular have often adapted to and taken advantage of these exotics to broaden their feeding habits. Ornamental palms such as *Phoenix canariensis, Washingtonia filifera* and *Washingtonia robusta* while initially confined to anthropogenic landscapes such as gardens, parks and streets, have been able to spread via birds and animals well beyond the confines of urban environments.

Introduced to the European nursery trade in the 1860s (Bailey, 1936, p. 63ff; Ishihata & Murata, 1971), and to Australia in the 1870s and 1880s, the Mexican fan palm or Desert Palm, *Washingtonia robusta* has become a major ornamental plant on a global scale, widely planted as a feature tree in private and public gardens, as well as an occasional street tree in many communities with a temperate climate (Spennemann, 2018b). Though much less invasive than other palm species, such as *Phoenix canariensis*, *Washingtonia robusta* is known to escape from horticultural settings and colonise natural areas. Endemic to semi-arid regions in northwest mainland Mexico and the southern Baja California (Cornett, 1989; McCurrach, 1960, p. 264f), *Washingtonia robusta* is regarded as naturalised not only in adjacent southern California and southern Arizona (Felger & Joyal, 1999), but also in subtropical areas such as southern Florida (Cornett, Stewart, & Glenn, 1986; Institute for Regional Conservation, 2016), Réunion (Indian Ocean) (Meyer, Lavergne, & Hodel, 2008), the North Island of New Zealand (Martin, 2009), and parts of Hawaii (Oppenheimer & Barlett, 2002). On the Australian continent it is regarded as naturalised in the Pilbara region, Western Australia (Pilbara Region, Keighery, 2010); evidence from Albury (NSW, Australia) presented in this paper demonstrates that it must also be regarded as naturalised in NSW.

Little is known about the dispersal potential of *Washingtonia robusta*. A review of dispersal vectors showed a number of vertebrate species feed on *Washingtonia* drupes, with some ingesting whole drupes and dispersing the seeds via regurgitation or defecation, in the Australian setting including Pied Currawongs (*Strepera graculina*) and fruit bats (*Pteropus poliocephalus*) (Spennemann, 2018c, 2018d). *Washingtonia robusta* have been noted as self-seeded plants in garden settings in Albury and Sydney (pers. obs.), but unlike *Phoenix canariensis, Washingtonia* do not seem to readily invade remnant bushland or agricultural areas. It is possible that their germination and initial establishment success, more so than that of *Phoenix canariensis*, relies on adequate moisture regularly provided in suburban gardens but which is seasonal in bushland settings. If such moisture is provided, it can establish in very marginal places such as cracks in the concrete pavements (Martin, 2009; Stein, 2010) and even in cavities in trees (Spennemann, 2018g). The long-term success of the seedlings is dependent on stable nutrient availability as well as lack of human intervention. Other factors that seem to influence establishment success in suburban gardens and peri-urban areas are the absence of grazing animals (primarily sheep and kangaroos), more friable and less compacted clayey soil, and property owners who tend to be tolerant of such exotic adventitious species.

In its natural habitat, *Washingtonia robusta* is strictly a plant of the semi-arid zone confined to a small area of the Sonora desert and the southern Baja California (Bomhard, 1950; Cornett, 1989, p. 94; Felger & Joyal, 1999; McCurrach, 1960, p. 264f; Wiggins, 1964). It occurs naturally in annually or irregularly flooded riparian habitats and palm oases, with the plants concentrated closest to water sources, on occasions near, but not in, permanent water or wet soil (Felger & Joyal, 1999). In Southern California, it has colonised riparian strips and aided by its seed shadow has crowded out other plants. On occasion the palm thickets have become so dense that some grew at the very stream edge with their trunks just in the water (Kelly, 2007). *Washingtonia robusta* has not been recorded as growing in the middle of ponds, lakes or flowing bodies of water in California or Mexico. It was therefore surprising to find plants growing in 1.5m deep water in the middle of the eastern maturation pond of Albury's waste water treatment works with no evidence of such palms growing in the adjacent bushland. This paper describes the distribution and nature of these plants and the possible vectors and mechanisms facilitating colonisation success.

## Biology of *Washingtonia robusta*

*Washingtonia robusta* Wendl. (Mexican Fan Palm) are monoecious, self-compatible plants that are solely propagated by seed (Barrow, 1998). They can have up to 30+ bright green, costapalmate fronds of 0.9 to 1.8 m with which are attached to the tree, each with a 1.2–1.5 m long plano-convex petiole. The red brown petiole exhibits curved spines on its entire length (Bailey, 1936, p. 63ff). A mature *Washingtonia robusta* will produce about 50 leaves annually (Brown & Brown, 2012). The trunk is usually covered with persistent dead fronds hanging from the crown, which, unless horticulturally removed, form a thick thatch ('skirt') surrounding the upper section of the trunk (Moran, 1978; Morton, 1998).

*Washingtonia robusta* typically grows to a height of 15-20 m with a trunk diameter of 0.6-1.2 m (up to 1.5m) (Broschat, 2017; Morton, 1998). The majority of palms will reach ages of less than 200 years, though specimens of 500 years have been estimated (Bullock & Heath, 2006). They reach maturity after they have reached at least 3m in height (Cornett cited in Martus, 2008, p. 25). The flower stalk ranges in length from 2 to 2.6 m, bearing numerous small, white bisexual flowers in compound clusters (Felger & Joyal, 1999). These result in infructescences (fruiting sprays) which ripen in autumn to early winter. Each drupe is small, black and ovoid-oblong to spherical fruit with a thin non-oily, carbohydrate rich pericarp and a single hemispherical seed (Brown & Brown, 2012). The drupes measure about 7-10mm in length with an average weight of 0.3g, while the seeds are about 4.7–6.5mm long and about 4.5–4.9mm thick with an average weight of about 0.1 g (Spennemann, 2018f). A single mature tree has been estimated to produce in excess of 300,000 drupes per year.

*Washingtonia robusta* seed germinate well within 14 days at soil temperatures of 25-35°C (Broschat, 2017; Brown & Brown, 2012; Mifsud, 1996). The fruit are eaten by a range of volant as well as terrestrial vectors. Passage through the gastro-intestinal tract enhances germination success of *Washingtonia filifera*, probably due to scarification by weak acids (Noto & Romano, 1987) and this is likely to be the case with *Washingtonia robusta* although no data was found on germination success. *Washingtonia filifera,* seeds and seedlings are allelopathic (Khan, 1982a, 1982b), giving the plant seedling a competitive edge over other vegetation, and this may also be the case with *Washingtonia robusta* although data has not been found. Once established, both species will do well with comparatively little water. *Washingtonia robusta* grows at the rate of about 0.6–0.9 m per year, but if well-watered, the palms reach annual growth rates of 1.8m, at least in the early stages (Morton, 1998; Muirhead, 1961, p. 41). Not well-watered *Washingtonia robusta* are on record as reaching 20m height under 30 years (Proschowsky, 1921).

## Albury study location

The artificial wetlands under discussion, the Kremur Street Sewerage Treatment Plant of Albury consists of two artificially created maturation ponds and a series of downstream wetlands that now form part of the Horseshoe Lagoon billabong system, located on the northern side of the Murray River floodplain, some 2.5 km west of the centre of Albury. While Horseshoe Lagoon and associated billabongs are a natural system, the two maturation ponds are artificial water bodies created by erecting retainment embankments and flooding a paddock previously used for grazing.

After alienation from the Indigenous owners of the land in the mid-1830s, the area first formed part of the grazing lease ‘Bungowannah Station’ (run nº 40, Thomson, 1848), after which the area close to Albury was reserved as part of the Albury Temporary Common (notified on 26 June 1868, Wilson, 1868). The land covering both maturation ponds as well as the sewerage works was then set aside for police purposes (‘police paddock’) on 21 November 1871 (Reserve Nº 853, Wilson, 1871) as revised on 6 October 1900 (Reserve Nº R 31,592, Hassall, 1900a, 1900b, 1900c). Given the existence of the wetlands, the area was converted into an area reserved for the protection of birds in January 1916 (Black, 1916). The eastern section, which comprises the vast majority of the first maturation pond, forms part of land set aside in March 1917 for the Albury Sewerage Works (Department of Lands, 1927; Strickland, 1917). The Kremur Street sewerage works were opened in May 1919 (Anonymous, 1919), with the maturation ponds constructed in the 1950s or early 1960s (Johnson, 2018). The plant was modified into a biological nutrient removal plant in late 1984 or early 1985 (Johnson, 2018) with further expansion of the scheme in the late 1990s (Abbey, 1994).

Aerial imagery of the Kremur Street sewerage works, taken in May 1949, shows the area as pasture with scattered eucalypts primarily along a drainage line, as well as a market garden in the east (Adastra Airways, 1949; Spennemann, 2018e). Today, evidence for the previous land use abounds in the form of dead eucalypts in the maturation ponds. Judging from the state of preservation of the dead trees (proportion of large vs small limbs vs. small branches), some of the trees were long dead well before the area was converted into maturation ponds, but the majority died off due to permanently water-logged soil following the flooding.

Setting aside rain water and minimal surface run-off, the ponds are only supplied with treated, screened and filtered wastewater from the Kremur Street plant. The water levels in the maturation ponds, which have not been drained since their construction, are more or less constant as they are regulated by an outlet weir at the north-western end of maturation pond Nº 2 (Johnson, 2018). Any fluctuations in water levels are limited to a variation caused by evaporation. The bottom sections of the ‘skirts’ of *Washingtonia robusta* exhibit a clean edge, confirming a more or less steady water level.

## Results

*Survey of Washingtonia robusta* in the Albury wetlands

In total, seven *Washingtonia robusta* palms were identified in maturation pond nº 1, three in maturation pond nº 2 and a group of palms on the southern peninsula dividing the ponds (Figure 1) (see Spennemann, 2018e for photographic documentation). Reference specimens were collected from a cluster of self-seeded plants on the peninsula and deposited in the CSU Regional Herbarium (see Spennemann, 2018a for documentation).

The location and current appearance of the palms, as determined by ground survey, are summarised in Table 1. The plants range from an almost 11m tall mature plant (P2, Figure 6) on the peninsula, to small seedlings of 1m height on the peninsula (P4) and small established plants in the ponds (Figure 3–Figure 5). One dead palm (W2) was also encountered in the western maturation pond (Figure 7). The plants in the maturation ponds were documented and photographed from the shoreline from various directions (Spennemann, 2018e). The plants growing in the ponds range in height from 2m to about 5m (Table 1).

Presence and dimensions over time are based on the interpretation of historic aerial imagery of varied quality, primarily sourced from the commercial service Nearmap™, from Albury City’s Mapping Portal (which includes custom-shot aerial imagery) and from GoogleEarth™. The quality of the images depends on the resolution of the aerial or satellite imagery, and the presence of cloud cover or sun reflections off the waterbodies (Table 2).

The crown diameters of the palms were classed in quarter-metre intervals. The observed size fluctuations are due to the variations in the aerial images and the accuracy of the embedded scales. Identification of *Washingtonia* on the aerial images was carried out in two ways: i) backtracking the presently existing palms in time, noting their presence and any changes to diameter; and ii) the identification of additional *Washingtonia.* This was possible as the foliage of

*Washingtonia* stood out as a very light green tone compared to the other small vegetation islands in the pond, and the presence of a shadow. The latter differentiates *Washingtonia* from sedge islands. The data compiled in Table 2 are expressed as timelines in Figure 2.

The mature tree (P2) is by far the oldest. As it is growing among eucalypts, it is not always readily distinguishable on the aerial images, especially at its smaller sizes when it would have been sufficiently obscured by the canopy of the eucalypts. The palm shows above / in the canopy from about 2010 onwards, which suggests that by that time the plant would have been about 5m tall (compare Figure 8).

*Washingtonia robusta* reputedly grows at about 0.6–0.9 m per year, once established (at ca 2yrs of age). If well-watered, the palm can, at least in the early stages, reach annual growth rates of 1.8m (Morton, 1998; Muirhead, 1961, p. 41; Proschowsky, 1921). Considering that the moisture regime at the site is not subject to climatic variation, but stable due the constantly flooded maturation ponds, the height gain of the plant between 2010 and 2018 suggests that plant P2 grew between 0.6 m and 0.7m per year. Projecting this growth rate back in time suggests that the plant seeded sometime in 2001 or 2002. The other six plants for which height data and aerial imagery exists (P1–P5, W1), grew at rates between 0.4 m and 0.55 m pa.


**Fig. 1.** Locations of the self-seeded palms shown on an aerial view of the maturation ponds of the Kremur Street Treatment Plant, Albury NSW. Aerial image flown 8 November 2017, image courtesy AlburyCity.

**Table 1. Location, nature, dimensions and distance to source palm of the documented Washingtonia and Phoenix Palms at Kremur Street wetlands, Albury**

| Specimen | Status | Stem | Height (m) | Crown (m) | Setting | Distance (m) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| *Washingtonia robusta* | | | | | | | | |
| East Pond nº 1 | immature | yes | 3.5 | 2.5 | ex perch | 318 | -36.085342 | 146.886768 |
| East Pond nº 2 | immature | yes | 2.5 | 2.5 | perch | 259 | -36.085306 | 146.88608 |
| East Pond nº 3 | immature | yes | 3.5 | 2.5 | perch | 227 | -36.084915 | 146.885858 |
| East Pond nº 4a | immature | yes | 4–5 | 2.5 | low perch | 195 | -36.08478 | 146.885544 |
| East Pond nº 4b | immature | no | 2 | 2.5 | — | 194 | -36.08478 | 146.885544 |
| East Pond nº 5 | immature | yes | 3.5 | 2.5 | perch | 213 | -36.085925 | 146.884853 |
| East Pond nº 6a | | not longer extant | | | perch | 112 | -36.084781 | 146.884594 |
| East Pond nº 6b | | not longer extant | | | perch | 112 | -36.084781 | 146.884594 |
| East Pond nº 6c | immature | no | 2.5 | 2.5 | perch | 112 | -36.084781 | 146.884594 |
| East Pond nº 7 | immature | no | 2.5 | 2.5 | perch | 123 | -36.084781 | 146.884594 |
| Peninsula nº 1a | immature | no | 2 | indet. | palm | 4 | -36.084411 | 146.883437 |
| Peninsula nº 1b | immature | no | 2 | indet. | palm | 4 | -36.084411 | 146.883437 |
| Peninsula nº 1c | immature | no | 2 | indet. | palm | 3 | -36.084411 | 146.883437 |
| Peninsula nº 1d | immature | no | 2 | indet. | palm | 2 | -36.084411 | 146.883437 |
| Peninsula nº 1e | immature | no | 2 | indet. | palm | 2 | -36.084411 | 146.883437 |
| Peninsula nº 2 | mature | yes | 10-11 | 3-4 | ex-perch | 0 | -36.084382 | 146.883500 |
| Peninsula nº 3a | immature | no | 1 | indet. | palm | 1 | -36.084353 | 146.883416 |
| Peninsula nº 3b | immature | no | 1 | indet. | palm | 1 | -36.084353 | 146.883416 |
| Peninsula nº 3c | immature | no | 2 | indet. | palm | 2 | -36.084353 | 146.883416 |
| Peninsula nº 3d | immature | no | 2 | indet. | palm | 2 | -36.084353 | 146.883416 |
| Peninsula nº 3e | immature | no | 2 | indet. | palm | 3 | -36.084353 | 146.883416 |
| Peninsula nº 3f | immature | no | 2 | indet. | palm | 3 | -36.084353 | 146.883416 |
| Peninsula nº 3g | immature | no | 2 | indet. | palm | 4 | -36.084353 | 146.883416 |
| Peninsula nº 4 | immature | no | 1 | 1.5 | perch? | 11 | -36.084302 | 146.883496 |
| West Pond nº 1 | immature | yes | 2 | 2.5 | perch | 135 | -36.083452 | 146.88245 |
| West Pond nº 2 | dead | no | 0.75 | 2 | perch | 232 | -36.082616 | 146.882024 |
| West Pond nº 3 | | not longer extant | | | perch? | 123 | -36.083744 | 146.882298 |
| *Phoenix canariensis* | | | | | | | | |
| Canariensis nº 1 | mature, male | yes | 4 | 5 | no perch | n/a | -36.082963 | 146.886351 |
| Canariensis nº 2 | mature, male | yes | 4 | 5 | no perch | n/a | -36.082959 | 146.886461 |
| Canariensis nº 3 | immature | no | 1 | 1 | perch | n/a | -36.08282 | 146.888867 |
| Canariensis nº 4 | immature | no | 1.5 | 2 | perch | n/a | -36.082806 | 146.8888 |
| Canariensis nº 5 | immature | no | 3 | 4 | perch | n/a | -36.082242 | 146.88844 |

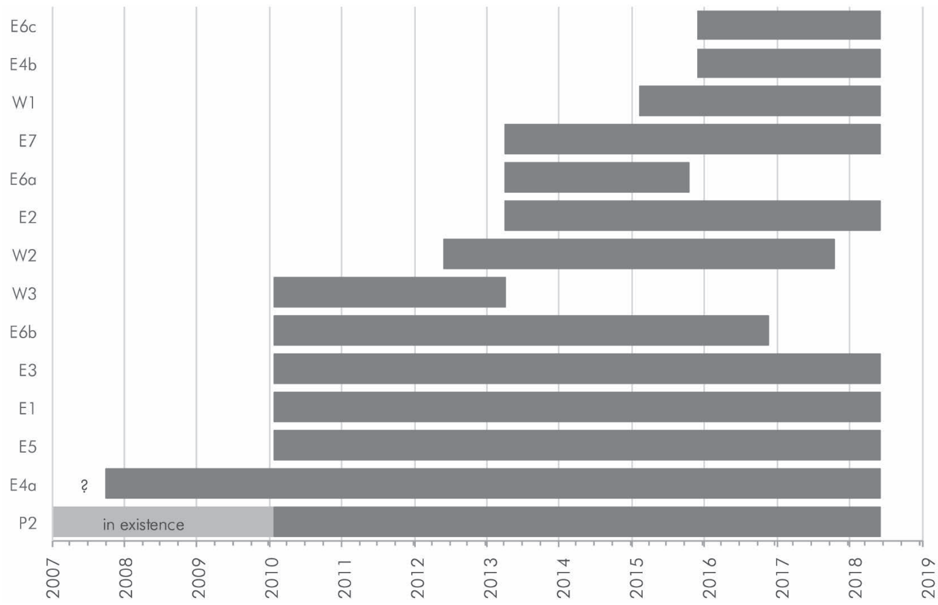


**Fig. 2.** Chronology of Washingtonia palms in the Kremur Street wetlands.

**Table 2. Crown diameters (in m) of Washingtonia in Kremur Street wetlands based on the interpretation of aerial imagery and ground inspection (1 June 2018).**

| Date | E1 | E2 | E3 | E4a | E4b | E5 | E6a | E6b | E6c | E7 | P1 | P2 | P3 | P4 | W1 | W2 | W3 | Image Quality | Image |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018, June 1 | 3 | 3 | 3.5 | 3.5 | 2 | 3.5 | — | — | 2 | 2 | 2 | 3.5 | 2 | 0.5 | 3 | dead | dead | ./. | Site Visit |
| 2018, May 1 | 3 | 3 | 3.5 | 3.5 | 2 | 3.25 | — | — | 2 | 2 | invis | 3.5 | invis | invis | 3 | dead | dead | very good | NearMap |
| 2018, Mar 11 | 3 | 3 | 3.5 | 3.5 | 2 | 3 | — | — | 2 | 1.75 | invis | 3.5 | invis | invis | 3 | dead | dead | very good | NearMap |
| 2018, Jan 20 | 3.5 | 3 | 3.5 | 3.5 | 1.5 | 3 | — | — | 2.5 | 1.75 | invis | 3.5 | invis | invis | 3 | dead | dead | very good | NearMap |
| 2017, Dec 22 | obs | 3 | 3.5 | 3.5 | 1 | 3 | — | — | 2 | — | invis | 3.5 | invis | invis | obs | dead? | dead | partly obscured | GoogleEarth |
| 2017, Nov 8 | 3.5 | 3.25 | 4.0 | 3.5 | 1 | 2.75 | — | — | 1 | 1.75 | invis | 3.5 | invis | invis | 3 | dead? | dead | very good | AlburyCity |
| 2017, Oct 10 | 3 | 3 | 3.5 | 3.5 | 1 | 2.75 | — | — | 2 | 1.75 | invis | 3.5 | invis | invis | 2.5 | 2 | dead | partly obscured | NearMap |
| 2017, Jun 13 | 3 | 3 | 3.5 | 3.5 | 1 | 2.75 | — | — | 1.5 | 1.75 | invis | 3.5 | invis | invis | 2.5 | 3 | dead | very good | NearMap |
| 2016, Nov 18 | 2.75 | 2.75 | 3.5 | 3.5 | 1 | 2.75 | — | 2 | 1.5 | 1.75 | invis | pres | invis | invis | 2.25 | 2.5 | dead | very good | NearMap |
| 2015, Nov 30 | 3 | 2.75 | 3.25 | 3.5 | 1 | 3 | — | 2 | 1.5 | 1.75 | invis | pres | invis | invis | 2 | 2.5 | dead | partly obscured | NearMap |
| 2015, Oct 15 | 3.25 | 2.5 | 3.25 | 3.5 | — | 3 | 1.75 | pres? | — | pres | invis | pres | invis | invis | 1.5 | 2.5 | dead | very good | AlburyCity |
| 2015, Feb 9 | 2.75 | 2.5 | 2.75 | 3.5 | — | 3 | 1.5 | 1.5 | — | 1.5 | invis | pres | invis | invis | pres | 2.5 | dead | very good | NearMap |
| 2014, Aug 20 | 2.5 | 2.5 | 2.75 | 3.5 | — | 2.75 | 2 | 2 | — | 1 | invis | pres | invis | invis | — | 2.5 | dead? | very good | NearMap |
| 2014, Feb 22 | 2.5 | 2.25 | 2.5 | 3.5 | — | 2.75 | 2.5 | 2.5 | — | pres | invis | pres | invis | invis | — | 2 | dead? | very good | (LPI, 2014) |
| 2014, Feb 2 | 2.5 | 2.5 | 2.5 | 3.25 | — | 2.75 | 2 | 2.5 | — | 1 | invis | pres | invis | invis | — | 2 | dead? | very good | NearMap |
| 2013, Apr 4 | 2.5 | pres | 2.5 | 3.25 | — | 2.75 | pres? | 2.5 | — | pres | invis | pres | invis | invis | — | 2 | 3 | very good | NearMap |
| 2012, Oct 5 | 2.5 | — | 2.0 | 3.25 | — | 2.75 | — | 2.5 | — | — | invis | pres | invis | invis | — | 2 | 3 | very good | NearMap |
| 2012, May 29 | 2.25 | — | 1.75 | 3.25 | — | 2.75 | — | 2.5 | — | — | invis | pres | invis | invis | — | 1.5 | 2.75 | very good | NearMap |
| 2011, Oct 2 | 1.75 | — | 1.5 | 3.25 | — | 3.0 | — | 2.25 | — | — | invis | pres | invis | invis | — | — | 2.5 | good | AlburyCity |
| 2011, Apr 16 | 1.75 | — | 1.25 | 3.25 | — | 2.75 | — | 2 | — | — | invis | pres | invis | invis | — | — | 2.5 | very good | NearMap |
| 2010, Nov 17 | 1.5 | — | obs | 2.75 | — | 2.5 | — | pres | — | — | invis | pres | invis | invis | — | — | 2.5 | partly obscured | NearMap |
| 2010, Jul 9 | 1 | — | 1.0 | 2.75 | — | 2.5 | — | 2.25 | — | — | invis | pres | invis | invis | — | — | 2 | very good | NearMap |
| 2010, Mar 13 | obs | obs | obs | obs | obs | obs | obs | obs | obs | — | invis | pres | invis | invis | — | — | ? | poor | GoogleEarth |
| 2010, Jan 24 | pres? | — | pres | 2.5 | — | 1.5 | — | 2.25 | — | — | invis | pres | invis | invis | — | — | 1.5 | very good | NearMap |
| 2009, Jul 11 | ? | — | ? | obs | obs | obs | ? | ? | ? | — | invis | pres | invis | invis | — | — | ? | very poor | GoogleEarth |
| 2007, Oct | — | — | — | 1? | — | — | — | — | — | — | — | ? | — | — | — | — | ? | poor | AlburyCity |
| 2004, Nov | — | — | — | ? | — | — | — | — | — | — | — | ? | — | — | — | — | ? | poor | AlburyCity |
| 2003, Feb 19 | — | — | — | ? | — | — | — | — | — | — | — | ? | — | — | — | — | ? | very poor | GoogleEarth |
| 2000, Nov 7 | — | — | — | ? | — | — | — | — | — | — | — | ? | — | — | — | — | ? | very poor | AlburyCity |

Codes: invis—not visible on aerial, obscured by other vegetation; obs—obscured due to clouds or reflections; pres—present but not measurable;

**Fig. 1.** Plant East nº3 as seen from south.

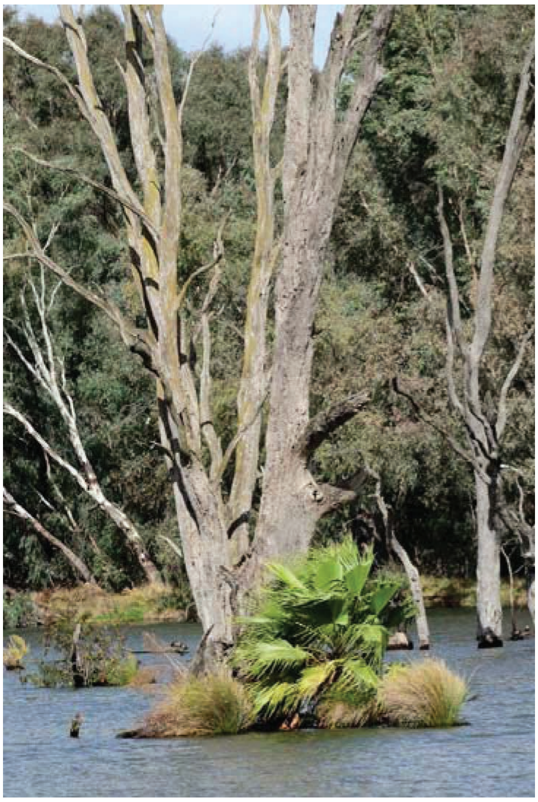

**Fig. 2.** Plant West nº 1 as seen from the northwest.

**Fig. 3.** Plant East nº4 as seen from north.

**Fig. 4.** The source palm (P2) as seen from the south.

**Fig. 5.** Plant West nº 2 as seen from the northeast.

**Fig. 6.** The source palm (P2) as seen from the west. Note the low self-seeded clusters to the right (P1) and left (P3).


**Fig. 7.** Appearance of the self-seeded Washingtonia palms (East nº3, 4, 6–9) on 22 February 2014 (top) and 8 November 2017 (bottom).

*Washingtonia dispersal and establishment processes*

*Washingtonia* plants growing in the Kremur Street maturation ponds and on the peninsula are all self-seeded and started growing from 2000. Successful establishment was dependent on the micro-graphic setting and on vectors for dispersal of the plant seed.

The maturation pond is a flooded pastoral landscape studded with dead eucalypt trees, most of which are now largely branchless and act as perches for numerous bird species. Sedges and other littoral vegetation grow at the base of these tree trunks providing some modicum of substrate on which *Washingtonia* can germinate (Figure 1, Figure 2). Fallen trees and branches, resting semi-submerged in comparatively shallow water, act as a traps for floating leaf litter and develop into shallow vegetation islets. None of these islets, however, have *Washingtonia* growing on them, with the possible exception of plant E4, which may have grown on or next to a semi-submerged log (comparing the November 2004 and October 2007 imagery). Similarly, the temporary establishment of plant W3 may have occurred on a semi-submerged log.

As the plants are growing in the middle of the maturation pond, birds, alighting on the perches provided by the dead trees, are responsible for the deposition of the seeds. A common feature of the successfully established plants is that all grow in areas with little or no shading. Examination of the shoreline, the peninsula and the larger vegetation islets showed the presence of other bird-dispersed weeds, such as blackberries (*Rubus* spp.) and figs (*Ficus* spp.) even in dense patches. *Washingtonia* seed does not appear to germinate or establish if it is choked by competing vegetation and concomitant lack of sunlight.

In California, *Washingtonia filifera* and *Washingtonia robusta* are also dispersed by fluvial activity (Talley, Nguyen, & Nguyen, 2012). Indeed, in the Albury setting, *Washingtonia robusta* seeds tend to end up in the street gutters and from there in the stormwater drains. As stormwater and sewerage are discharged and treated differently, however, none of these seeds are likely to end up in the sewerage treatment plant, let alone in the maturation ponds (as the outgoing water is screened and filtered). All seeds in the ponds would have been introduced by vertebrate vectors.

Vertebrate species, both volant and terrestrial feed on *Washingtonia* drupes and disperse their seeds. In Australia the only vectors on record are the Pied Currawong (*Strepera graculina*) and Grey-headed flying fox (*Pteropus poliocephalus*) (Spennemann, 2018c). Currawongs, ingest fruit as a whole and then fly to a nearby perch to digest the meal in the crop and regurgitate the indigestible elements such as seeds and part of the pericarp (Spennemann, sunpubl.).

**Table 3. Potential volant vectors observed at the Kremur Street Parklands and adjacent Horseshoe Lagoon (HS)**

| Common name | Scientific name | consumption | perching | vector status |
|---|---|---|---|---|
| Greylag Goose (Domestic type) | *Anser anser* | probable | possible | unlikely |
| Spotted Dove | *Spilopelia chinensis* | possible | possible | possible |
| Crested Pigeon | *Ocyphaps lophotes* | possible | probable | possible |
| Pacific Koel (HS) | *Eudynamys orientalis* | probable | unlikely | possible |
| Noisy Miner | *Manorina melanocephala* | possible | likely | probable |
| Red Wattlebird | *Anthochaera carunculata* | possible | likely | probable |
| White-plumed Honeyeater | *Lichenostomus penicillatus* | probable | likely | probable |
| Blue-faced Honeyeater | *Entomyzon cyanotis* | probable | possible | possible |
| Little Friarbird | *Philemon citreogularis* | possible | likely | probable |
| Noisy Friarbird | *Philemon corniculatus* | possible | likely | probable |
| Australian Magpie | *Cracticus tibicen* | possible | likely | probable |
| Pied Currawong | *Strepera graculina* | documented | likely | likely |
| Black-faced Cuckooshrike | *Coracina novaehollandiae* | probable | likely | probable |
| White-bellied Cuckooshrike | *Coracina papuensis* | probable | unlikely | possible |
| White-winged Triller (HS) | *Lalage tricolor* | possible | probable | possible |
| Crested Shrike-tit | *Falcunculus frontatus* | possible | possible | possible |
| Olive-backed Oriole | *Oriolus sagittatus* | possible | possible | possible |
| Australian Raven | *Corvus coronoides* | documented | probable | probable |
| White-winged Chough (HS) | *Corcorax melanorhamphos* | possible | possible | possible |
| Common Blackbird | *Turdus merula* | documented | unlikely | unlikely |
| Common Starling | *Sturnus vulgaris* | documented | probable | probable |
| Common Myna (HS) | *Acridotheres tristis* | documented | possible | unlikely |

Given the small size of the drupe (diameter 9–10mm), however, a much greater range of vectors can be inferred. In total 99 bird species are on record for the Kremur Street Parklands (Cornell Lab of Ornithology, 2018b), with an additional 26 species observed at the adjacent Horseshoe Lagoon (Cornell Lab of Ornithology, 2018a). Of these, 101 are pure waterbirds or exclusively insectivores, which can be ruled out as potential vectors for *Washingtonia* drupes/ seeds.[1] The remainder have been classified in terms of their likelihood to act as effective vectors of the *Washingtonia* growing in the maturation pond based on whether they have been known to ingest *Washingtonia* or *Phoenix* drupes (Spennemann, unpubl. data), or like-sized, large seeded fruit (Barker & Vestjens, 1989) (Table 1 'consumption') and whether they are likely to perch on isolated, very exposed dead trees or alight on small (<1 $m^2$) vegetation patches in the maturation pond (Table 1 'perching'). The majority of these will alight on isolated trees or tree trunks with good visibility and some height to aid in emergency take off. There they process their meal and regurgitate the indigestible parts. The self-seeded palms on semi-submerged logs can be explained in that birds, that land on these to drink void indigestible elements by regurgitation before drinking. The domestic geese originate from a property near Horseshoe Lagoon and are spatially confined to that lagoon, away from the area where the *Washingtonia* occur.

## Discussion

*Long-term success*

At the time of on-ground inspection one of the palms (W2) was dead (Figure 5). The remains showed at least 13 fronds, indicating it had thrived for some time. Based on aerial imagery, the plant existed from 2012 to 2017 and seems to have originally established on a semi-submerged trunk. The cause of the palm's death is not evident as the terminal growth bud is well above the water. It is possible that the palm ran out of nutrients.

Another example of establishment and subsequent failure are palms East 6a and 6b. Both grew under the perch of a dead eucalypt. Plant 6b established in ca 2010 and was followed to the south by plant 6a in ca 2013. Both were thriving in 2014 (Figure 7 top) but by late 2015 both had died and another *Washingtonia robusta* (East 6c) had emerged closer to the base of the dead eucalypt tree. This palm is still extant today (Figure 7 bottom). Today nothing remains of plants 6a and 6B and it remains unclear why they died.

The plants on the peninsula are growing on clayey soil, ca. 0.5m above the water level, while the palms in the pond are growing on an unspecified substrate. It can be surmised that the initial establishment occurred on substrate accumulated on a semi-submerged log or on debris trapped at the base of the trunk that serves as perch. Over time the roost must have reached the soft bottom of the maturation pond as the stability of the palms cannot be explained otherwise.

Worth noting is the differential growth rates between the palms growing on the peninsula (0.6–0.7m pa) and those growing in the maturation ponds (0.4–0.5m pa). This differential growth can be explained in terms of the availability of soil nutrients and the inhibiting factors of water-logged soil. *Washingtonia robusta* reputedly exhibited retarded growth when over-watered or planted in wet soils (Meerow, 1994). Clearly, the document growth rated of 1.8m per year among well-watered *Washingtonia robusta* (Morton, 1998; Muirhead, 1961, p. 41) are contingent on ample supplies of nutrients and soil substrate as water availability alone is not a factor.

The palms growing in the maturation ponds at the Albury Sewerage Works highlights the adaptability of the palm. The only other mention of *Washingtonia robusta* growing in water comes from Malta in the Mediterranean, where Mifsud (1995) observed two mature palms growing in a pond in the San Anton Gardens.

*Other self-seeded palm species nearby*

Two well-established, mature *Phoenix canariensis* are located in the grassed area north of maturation pond Nº 1. Both are male specimens with similar size (5 m diameter, 4m height). Given that neither palms is located near any perch trees or overhead wires, they are likely to have grown from seeds that were either dropped mid-flight by avian vectors, or, more likely, deposited in scats by terrestrial vectors such as foxes (Spennemann, 2018d). Three additional, immature *Phoenix canariensis* were noted in the cluster of eucalypt trees to the north of maturation pond Nº 1. Two of these palms were close to the southern edge of the wooded area, while the third was at the edge of an opening near the northern margin (Spennemann, 2018e).

The absence of *Washingtonia robusta* in the areas beyond the maturation pond is striking. The reasons are not self-evident, as both *Phoenix canariensis* and *Washingtonia robusta* are well represented as self-seeded plants in suburban Albury. A similar situation was observed in open agricultural settings at Alma Park (Southern Riverina of NSW) where *Phoenix canariensis*, originating from a number of source trees, widely established itself since the 1950s, whereas a *Washingtonia robusta*, planted in 1906 (at the same time as the homestead), produced no viable offspring.

Unlike *Phoenix canariensis, Washingtonia robusta* may have trouble germinating and establishing in areas of higher competition with groundcover grasses, especially those which have allelopathic capacity (Downer & Hodel, 2001). The same applies to seeds dropped under perch trees, as

1 The Spiny-cheeked Honeyeater (*Acanthagenys rufogularis*), which was identified for Horseshoe Lagoon (Cornell Lab of Ornithology, 2018a) was omitted from the table as its presence is very unlikely (pers. comm. D Watson).

similar allelopathic potential is exhibited by several species of eucalypt (Chu et al., 2014; Zhang & Fu, 2009) as well as *Callitris* (Harris, Lamb, & Erskine, 2003).

No data exist for *Washingtonia robusta*, but as both seeds and seedlings of its congener, *Washingtonia filifera,* are allelopathic (Khan, 1982a, 1982b), it can expected that this is the case for *Washingtonia robusta* as well. The allelopathic potential of a *Washingtonia robusta* seed and seedling appears to be outcompeted by that of other plants due the small volume of the *Washingtonia robusta* seed and the small area of its seedling. In areas of non-competition it is also possible that *Washingtonia robusta* may germinate but fail to successfully establish on compacted clay soil, while *Phoenix canariensis* with its larger seed mass has that ability. Once successfully established as a seedling, the plant has a high chance of survival unless subjected to grazing.

## Implications

Setting aside a discussion on the merits of novel ecosystems as 'valid' environmental states (Hobbs, Higgs, & Hall, 2013; Miller & Bestelmeyer, 2016; but see Murcia et al., 2014), it needs to be asked from a management perspective whether the colonisation of the wetland at Albury by *Washingtonia robusta* is beneficial or detrimental. Clearly, *Washingtonia robusta* do not rapidly invade the bushland surrounding the wetlands; the failure to establish in areas where other invaders (blackberry, fig) thrive, demonstrates this well. Establishment seems to be random (P) and only successful in the event of seed rain (*i.e.* underneath P2). The colonisation of spaces underneath perches in open water seems to be successful, albeit not on a large scale. No other plant seems to successfully establish at such locations, suggesting that *Washingtonia robusta* adds habitat variation rather than detract from it.

Unlike the dense crown of pinnate fronds of *Phoenix canariensis*, which provides roosting habitat for numerous birds, marsupials and rodents, the sharp spines that line the upper edges of the petioles of *Washingtonia robusta* act as a major faunal deterrent. Consequently, colonisation by *Washingtonia robusta* does not add to habitat until such time that the plants have developed a deposit of old, dry leaves that form the 'skirt.' Once this has occurred, *Washingtonia robusta* provides sheltered nesting habitat for several species.

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