African Olive (*Olea europaea* subsp. *cuspidata*) as an environmental weed in eastern Australia: a review

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Abstract: African Olive, *Olea europaea* subsp. *cuspidata* (Wall. ex G.Don) Cif. (family Oleaceae) is a dense-crowned tree introduced into Australia for horticulture in the mid 19th century. In recent decades, African Olive has become an aggressive woody weed, capable of forming a dense and permanent canopy in a wide range of vegetation types in south-west Sydney and beyond. Characteristics of African Olive invasion in south-west Sydney, and its seed dispersal by frugivorous birds are consistent with experience from Norfolk Island and Hawaii. We use records and aerial photographs from Mount Annan Botanic Garden and other bushland areas in south-west Sydney to describe the invasion stages and impacts of African Olive. The capacity for African Olive to establish in both temperate and subtropical zones, underlie the potential for spread well beyond current distribution in New South Wales. Research is now required to further develop control techniques and ecological restoration strategies for areas of heavy African Olive infestation. Mapping of current locations and a coordinated control strategy for African Olive is required to prevent future permanent loss of native plant diversity.

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Introduction

European Olive (*Olea europaea* subsp. *europaea*) is well documented as an environmental weed in Australia, particularly in the Adelaide region of South Australia where cultivated trees have been abandoned and their progeny have established in remnant bushland (Spennemann & Allen 2000a, Crossman 2002). African Olive (*Olea europaea* subsp. *cuspidata*) was introduced to Australia in the mid 19th century for horticultural purposes, and is now an aggressive weed in the Camden—Campbelltown and Hunter Valley areas of New South Wales, as well as on Norfolk Island. It is highly invasive in drier woodlands, riverine environments, coastal headlands and dune systems (Muyt 2001). African Olive is a declared noxious weed in NSW and South Australia, and listed nationally as a potential environmental weed (Csurches & Edwards 1998). African Olive outcompetes established native vegetation, casting dense shade which prevents the regeneration of native plants (DEH 2004). Following an extensive vegetation mapping project in western Sydney, Tozer (2003) identified African Olive as a management problem requiring urgent attention to ensure the conservation of biological diversity. In contrast to studies on the invasiveness of the cultivated European Olive, African Olive has received relatively little research attention on its ecology and biology as an environmental weed under Australian conditions.

In this review we describe the taxonomy of African Olive, its history of introduction into Australia and subsequent distribution, and key aspects of its biology that may contribute to its success as an environmental weed. We then describe a model of the stages of African Olive invasion, based on evidence from aerial photographs, observations and archives at Mount Annan Botanic Garden, Sydney and in bushland remnants across western Sydney over a 15-year period. Botanical names used follow those used by the National Herbarium of New South Wales.

African Olive — botanical relationships and biogeography

African Olive is part of the *Olea europaea* complex, which includes the edible European Olive, long-cultivated throughout the Mediterranean region. The *Olea europaea* complex extends from the Canary Islands and Madeira westwards across the Mediterranean, and south-west Asia to the Sino-Himalayan region, and south through eastern Africa to southern Africa (Green & Wickens 1989). African Olive is part of a tropical wild olive group, geographically isolated from their Mediterranean relatives and adapted to totally different climates (Zohary 1995).

The genus *Olea* occurs across a very wide geographic range with 33 species and nine subspecies described (see Green (2002) for a taxonomic account of the genus). In Green's (2002) recent revision of *Olea*, the name *Olea europaea* subsp. *cuspidata* is proposed for the wild olive occurring in South to North-East Africa and southwest Asia, and naturalised in Hawaii, Australia, New Zealand and Norfolk Island. In Australia both the European Olive (*Olea europaea* subsp. *europaea*) and African Olive (*Olea europaea* subsp. *cuspidata*) have naturalised.

In NSW African Olive was previously known as *Olea africana* and more recently *Olea europaea* subsp. *africana*. It is readily distinguished from European Olive by the presence of a hooked leaf apex and a lower leaf surface which is green or yellowish brown (Harden 1992) (see Table 1 for diagnostic characteristics).

Ecology of African Olive in its native range

The major area of natural distribution for African Olive is eastern Africa, where it extends throughout the eastern African states from the southern tip of Africa to the north-east regions. It is commonly recorded for the countries of Tanzania, Kenya, Ethiopia, Mozambique, Sudan, Namibia, Somalia and South Africa. From eastern Africa, the distribution extends into the Middle East region with occurrences in Yemen and Saudi Arabia. A significant Asian centre of African Olive distribution is northern India, Afghanistan, Pakistan and Kashmir. The most easterly natural distribution is China, particularly the drier parts of Yunan and Sichuan (Green 2002).

In its native range African Olive is a small-medium evergreen tree which grows in a wide range of habitats, including open woodlands, rocky mountain slopes and along watercourses (Table 2). African Olive trees have a dense bushy habit and typically grow to 5–10 m in height (Palgrave 1983). When growing under ideal conditions such as stream banks, trees can attain a height of 15–18 m. In dry exposed conditions trees develop a bushy, rounded habit with a dense canopy and gnarled trunk. Grey-brown flaky bark develops on the older branches. Sweetly scented flowers are produced in the summer months (October – December in its native range) and are 6–10 mm, greenish white in colour and held in loose axillary heads. The fleshy ovoid fruits develop from March to July (native range) and are 7–10 mm in size turning dark brown to black on maturity. Fruiting trees in their natural

Table 1: A comparison between the two naturalised Olive species in Australia.

Taxon	Leaf characteristics	Field characteristics/comments
African Olive		
Olea europaea subsp. *cuspidata*	6–10 cm long 10–25 mm wide Undersurface pale green – yellowish brown Leaf tip with hooked apex Mid veins yellowish green.	Fruit – purple black thinly fleshed drupe, round 6–7 mm diameter Dense multi – trunked tree with dark green glossy foliage. Naturalised/weedy in coastal districts
European Olive		
Olea europaea subsp. *europaea*	3–7 cm long 8–10 mm wide Undersurface whitish – silver grey Hooked leaf apex absent Leaf margins slightly recurved	Fruit – purple/black oval drupe 15–25 mm long x 6 mm diameter. Dense multi – trunked tree with dark green/silver underside foliage sheen. Naturalised in inland districts with dry climate

Table 2: Examples of natural habitat types for African Olive – Data obtained from records of the East African Herbarium, Nairobi.

Location	Habitat description
Ketumbane Mtn Tanzania	A much branched evergreen tree up to 16 m tall. Growing in association with *Juniperus procera* on the steep sides of a volcanic mountain. Altitude 1981 mASL. Common at the lower and drier altitudes.
Ufipa region, Tanzania	Mbizi Forest. A mountain edge on the Rukwa Rift escarpment. Tall forest tree 12–16 m. Also present with fringing vegetation. Dominant upper storey trees include *Entandophragma, Euphorbia, Polyscias*. Lower storey trees include *Dombeya, Croton, Lianes, Toddalia*. Altitude 2286 mASL.
Matthews Range, Samburu region, Kenya	Upland forest on basement complex with *Juniperus, Croton megalocarpus* and *Encephalartos tegulaneus* in drier areas, *Podocarpus gracilis* and *P. milanjiana* in moister areas. Altitude 1752 mASL.
Longonot, Nakuru region, Kenya	One of the commonest trees on lava flows, usually in pockets of soil on the crests of ridges. May be up to 10 m high. Altitude 1951 mASL.
Marafara, Kilifi region, Kenya	Tree 5 m. Coastal thickets with *Combretum hereroense, Terminalia prunioides, Sideroxylon, Thespesia*. Altitude 80 mASL.
Virunga National Park, Semliki River, Dem.Republic of Congo	Woodland on banks of river and grassy plateau just above it. Dominant shrub/tree along much of the river. Associated with *Euclea, Grewia* and *Acacia sieberiana*. Altitude 950 mASL.

Fig. 1. African Olive fruits (7-10 mm diameter) ripen during winter and are attractive to birds**.**

Fig. 2. Birds consume the ripe black African Olive fruits, digesting the fleshy outer covering and voiding the hard woody seed endocarp (3-5 mm diam). The fruit and seed is well within the optimal size range for dispersal by a range of Australian native and introduced bird species.

habitat attract a range of fruit-eating birds eg. pigeons, parrots, louries, mousebirds, bulbuls and starlings (Venter & Venter 1996). The fruits are also eaten by monkeys, mongoose and humans (Pooley 1993). The leaves are used to make a tea, a gargle for sore throats and an eye lotion (University of Pretoria 2004). Wood produced is close grained, strong and very hard (Palgrave 1983). Due primarily to over exploitation of its useful timber, African Olive is considered threatened in some African regions and is a protected tree in the Northern Cape, Free State and North-west Provinces of South Africa.

History of introduction to Australia

African Olive was first introduced to Australia in the mid 19th century as an ornamental and hedging plant (Muyt 2001) and as a rootstock for the European olive; which later proved to be unsuitable (Spennemann & Allen 2000a). Tracing the general horticultural introduction and use of African Olive in Australia is complicated by the lack of consistent nomenclature, particularly that used in old nursery catalogues, where there is a tendency to group African Olive with the European Olive. African Olive does not produce fruits of commercial value, and is also listed in nursery catalogues as the hedging plant *Wild Olive*.

Olives are recorded as one of the earliest plant introductions to Australia, with European Olive (*Olea europaea*) planted at Elizabeth Farm, Parramatta by the agricultural pioneer John Macarthur in 1805 (Dellow 1987). The introduction of African Olive in the Cumberland Plain region, south west of Sydney (now a major centre of African Olive spread), is closely linked to John Macarthur, and his sons John and William, and the development of the famous *Camden Park* estate, near Camden, in southwestern Sydney. African Olive appears to have been planted as a hedge for the original vineyard, established in the 1820s, and planted specimens, now of great size, and consistent with the original planting layout, are still present at *Camden Park* (C.Mills, pers. comm.)

An established nursery operated at *Camden Park* during the mid 19th century and contemporary catalogues listed many African species that have since become environmental weeds. The Macarthurs' 1843 *Catalogue of Plants Cultivated at Camden* listed '*Olea europaea* (six varieties)' presumably including African Olive under this name. African Olive was extensively planted as a hedge throughout the Camden area; these trees can still be seen at historic properties, lining paddocks and driveways and were an important element of these 19th century 'wilderness' gardens (Landarc 1993).

From the 1930s to the 1970s, African Olive was available in the NSW nursery trade as a hardy small tree or hedge plant and is listed in catalogues from leading nurseries such as the NSW Forestry Commission and Swane's. The first indication of the weed potential of African Olive is evident in the 1976 Forestry Commission catalogue which lists *Olea africana* "Golden Olive" as *a useful small tree that withstands a good deal of drought and heat and makes an excellent hedge*; with a warning that *it can become a very bad weed in some areas e.g. Cobbitty (near Camden)* (Forestry Commission 1976). African Olive is no longer grown commercially or widely available in the nursery trade, though the Australian Association of Bush Regenerators list African Olive as a major weed that is still cultivated in gardens near bushland (AABR 2004).

Distribution of African Olive in Australia

African Olive is established as an adaptable and persistent environmental weed in eastern Australia, capable of growing in both temperate and sub-tropical regions. Below is a short summary of the worst areas of infestation.

Western Sydney - NSW

The Camden – Campbelltown area on the southern edge of the Cumberland Plain in western Sydney is the most established centre of African Olive occurrence in Australia. Here historic properties have provided multiple source locations for the spread of African Olive, facilitated by frugivorous birds. It was first noted as a potential problem weed in the area around the mid -1970s, by which it time it formed shrubby thickets on the steeper slopes and hills in the Camden – Cobbitty area, particularly on the Razorback Range (Forestry Commission NSW 1976, D. Benson, pers. comm). By the 1980s it was described as a major invading weed of grazing parkland in the Camden/Campbelltown area (Dellow 1987). The rapid expansion of African Olive in the Camden – Campbelltown area from the 1980s has been documented at Mount Annan Botanic Garden. With the cessation of grazing, African Olive has spread throughout Mount Annan Botanic Garden beginning with scattered occurrences over 20 hectares in 1985 to a present coverage of 80 hectares, with some sections now developed into mature (>15 years age) pure stands on steeper sites. From established populations in south-west Sydney, African Olive is now spreading northwards to other areas of the Cumberland Plain, primarily along roadsides and beneath powerlines into the Penrith and Windsor areas.

The expansion of African Olive in western Sydney is significant, as the region contains thirteen Endangered Ecological Communities listed under the *NSW Threatened Species Conservation Act 1995*. Native vegetation on the Cumberland Plain has been extensively cleared since European settlement, with intact native vegetation now reduced to 13% of the landscape (NPWS 2006). Major African Olive occurrences are mapped for the Camden, Wollondilly, Liverpool, Campbelltown and Penrith local government areas (LGAs) (NPWS 2002), and show a preference for heavily disturbed sites on shale-derived soils with a landslope of >20 degrees (Roberts 1999). African Olive poses a major threat to the long term existence of Cumberland Plain Endangered Ecological Communities, and is specifically noted as a threatening woody weed in the NSW Scientific Committee determinations for Western Sydney Dry Rainforest and River Flat Eucalypt Forest on Coastal Floodplains. Over 1300 ha of dense African Olive understorey has been identified in Cumberland Plain vegetation mapping (NPWS 2002) with substantial infestations occurring in the Endangered Ecological Communities, Cumberland Plain Woodland (985 hectares) and Moist Shale Woodland (208 hectares). Recent mapping of major African Olive infestations throughout the Cumberland Plain using 2000 satellite imagery (P. Cuneo unpublished data) has identified 4000 ha, where African Olive occurs as a dense and dominant understorey.

African Olive occurs as scattered occurrences in the Kurrajong – Grose Vale area and Scheyville National Park. In the Ryde LGA, where African Olive is a declared noxious weed, infestations appear to have originated from historic plantings at Brush Farm, with current spread now limited to several small bushland parks (A. Smith pers. comm.).

Illawarra region , NSW

African Olive is found in the Kiama, Dunmore and Bombo districts (P.Cuneo, pers obs.) and is listed as one of the significant woody weeds that threaten the long-term viability of the listed Illawarra Subtropical Rainforest Endangered Ecological Community (NSW Scientific Committee 2002). Dense infestations of African Olive occur north of Lake Illawarra in the Berkeley Hills area, in conjunction with remnant stands of Illawarra Subtropical Rainforest.

Hunter Region, NSW

African Olive is considered to be one of the most serious environmental weeds in the Central Hunter region, because of its ability to completely alter ecosystems through crowding and shading (Peake 2005). Vegetation mapping for the Central-Upper Hunter region (Peake 2005) describes four Spotted Gum/Box/Ironbark grassy woodland communities of regional conservation significance which are under threat from African Olive. African Olive is considered to be a serious threat to the Lower Hunter Spotted Gum – Ironbark Forest Endangered Ecological Community (Peake 2005). Dry rainforest vegetation in the Upper Hunter region includes native Oleaceae species, which are also at risk from African Olive invasion. Maitland LGA contains a major infestation of African Olive, with an estimated 15 000 hectares (B. Worboys pers. comm.) centred in the Lochinvar – Maitland Vale districts. African Olive infestation in the Maitland area ranges from scattered plants to ~2000 ha of established dense monocultures on hilly terrain. Observations by local government weed control officers confirm that African Olive is now well established, and has spread significantly over the past five years in the Cessnock, Maitland and Port Stephens local government areas. The characteristic distribution and spread of African Olive along roadsides is reported from the Hunter region, particularly where there are overhead powerlines, fencelines and large trees that provide perch sites for birds. Other Hunter region locations include Rothbury, Hinton and Woodville where African Olive densities are low and in the early stages of invasion. (G. Pritchard, B. Shepherd pers. comm.). African Olive also occurs in the riparian zone along the Hunter River (M.R. Leishman pers. obs.), including highly saline creeklines dominated by Swamp Oak (*Casuarina glauca*).

North-western slopes, NSW

African Olive commonly occurs in townships throughout the North-western slopes region (Hosking pers comm.) but has not established as large infestations. Locations for African Olive include Oxley Park, Tamworth and Attunga State Forest (Hosking & James 1998), and Nundle and Woolomin (Lawler pers. comm.).

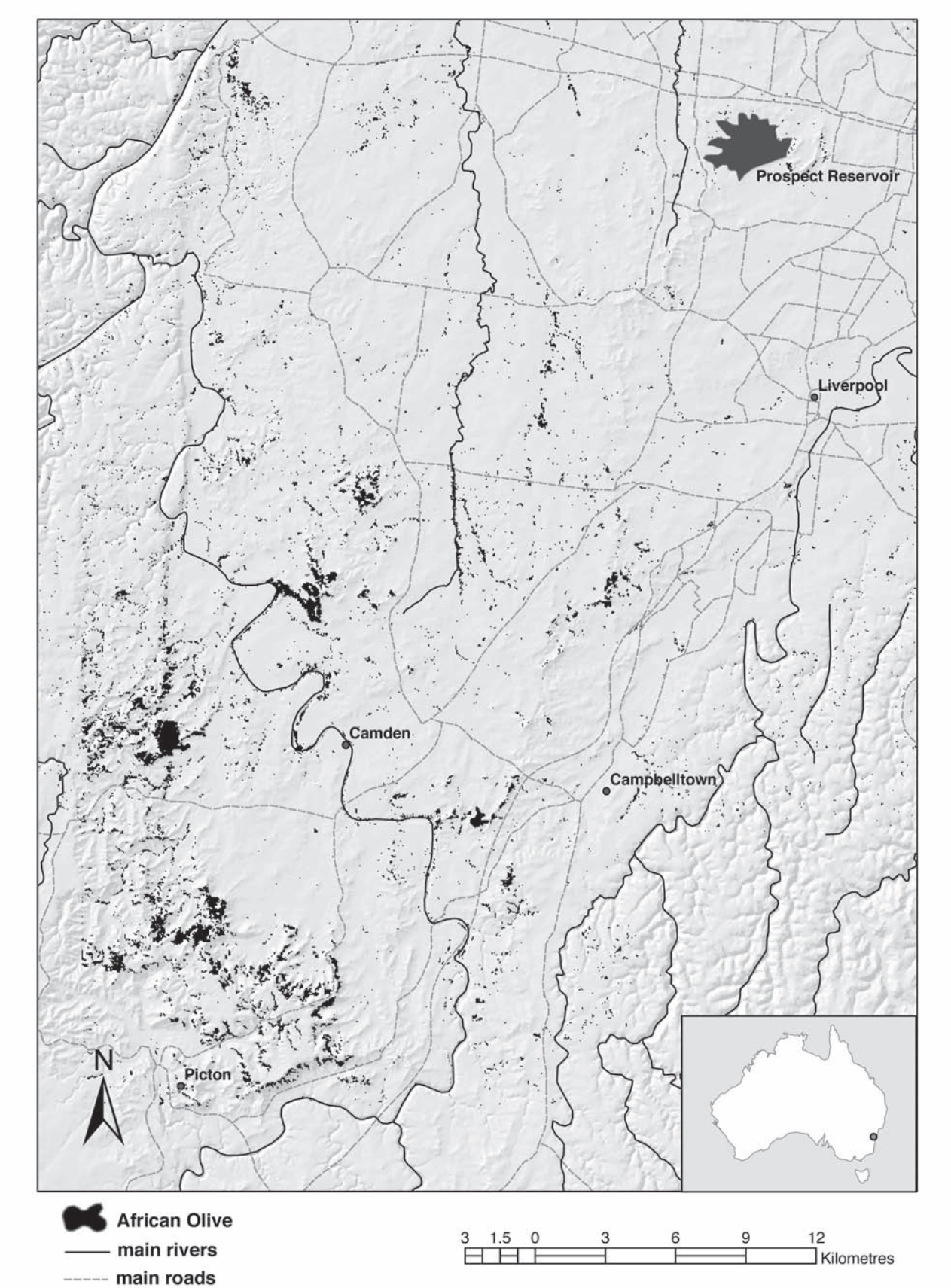

Fig. 3 African Olive is well-established on the clay soils and hilly terrain of south-western Sydney. It is widely established in the Camden region, and has spread rapidly since the 1980s. Dense infestations now threaten fragmented native vegetation. Source: Landsat 2000 imagery

North Coast, NSW

African Olive is reported from dry rainforest in the Wollongbar area near Lismore (D. Bailey pers. comm.). Old specimens of African Olive (estimated to be at least 80 years old) exist at the Agriculture Department site at Wollongbar with some spread of the population into adjacent rainforest remnants (M. Delaney pers. comm.). A single large tree has been recorded in subtropical rainforest at Eltham, but has not yet displayed invasive tendencies.

Norfolk Island

African Olive is one of the worst woody weeds on Norfolk Island, occurring as isolated plants, scattered clumps, and impenetrable thickets (DEH 2004). Norfolk Island was settled by Europeans in 1788 and considerable deforestation occurred soon after (Hill 2002). As the native forest was cleared African Olive became a major weed, and quickly established dense closed monoculture forests. The dense forests of African Olive have impacted on the habitat of the rare Norfolk Island Green Parrot, with African Olive forest supporting the lowest number of nesting sites. However, African Olive seeds may now form a significant part of the diet of newly-fledged juveniles of this species. (Motte & Hall 1988; Davidson 1997). The establishment of African Olive as major woody weed species in the subtropical climate of Norfolk Island (average annual rainfall 1325 mm, range 784–1856 mm) is a clear indication of its adaptability to climatic zones outside current distribution in mainland Australia.

Adelaide Hills, South Australia

African Olive has also become naturalised in the Adelaide Hills region, and is recorded for Shepherds Hill Recreation Park (AVH 2006). However European Olive is much more prevalent, being widely described as the most serious weed in the Adelaide Hills (Muyt 2001). European Olive appears to be better adapted to the Mediterranean climate of the region than African Olive (D. Bass pers. comm). Heavy infestations of European Olive in the Adelaide Hills do not form the same dense continuous canopy that characterises African Olive infestation in NSW (P. Cuneo pers. obs.).

African Olive invasions outside of Australia

Hawaiian Islands

African Olive is naturalised on the islands of Hawaii, Maui and Kaua'i, where it was planted as windbreaks and hedges (Starr et al. 2003). The pattern of introduction and spread is remarkably similar to the spread in Australia. For example, the fruits are readily dispersed by birds, and plants establish along roadsides, disturbed woodlands and pastures from sea level up to 1500 m elevation. African Olive was first collected as a garden escape on the island of Hawaii in 1965. By 1992 it was found on over 6000 ha at the Hawaii Volcanoes National Park; this infestation is thought to have spread significantly following the removal of cattle (Santos, Kageler et al. 1992).

New Zealand

African Olive is listed by the Bay of Plenty Regional Environment Council as a weed of open coastal scrub and modified sites near native forest margins. It occurs on both inshore and offshore islands such as Raoul Island (Kermadec Island group), where it is showing aggressive weed tendencies similar to on Norfolk Island (BPRC 2006). An African Olive eradication program is currently being implemented on Raoul Island by the New Zealand Department of Conservation (Ambrose pers. comm.). Occasional occurrences have been reported around Auckland city and the inner Hauraki Gulf islands where it displaces coastal shrubs and trees (BPRC 2006).

Weed Ecology of African Olive in Australia

Seed development and soil seedbanks

Flower and fruit development for African Olive in Australia closely matches that of European Olive, described by Crossman (2002). Individual African Olive trees produce fruit on a supra-annual cycle of 2–3 years depending on seasonal conditions. Flower initiation commences during late spring (October) with the small (5 mm) creamy white flowers appearing in mid summer (December). Pollination under Australian conditions is not documented, but is considered to be primarily by wind (as for European Olive) and a range of insects. The small green fruits develop during late summer and ripen during winter. Fruits are 6–7 mm in diameter at maturity and change from green to purple-black in colour when ripe. Trees at the early mature stage are capable of producing more than 25 000 fruits (P. Cuneo unpub. data). Fruit maturation within stands is asynchronous, with ripe fruits produced on individual trees from June – September. Baskin and Baskin (1998) report that *Olea africana* (syn. *Olea europaea* subsp. *cuspidata*) seed exhibits morphophysiological dormancy, ie before germination can occur the embryo must grow to a specific size, and the physiological inhibiting mechanism of the embryo must be broken.

Freshly collected African Olive seed has high viability, up to 88% (P. Cuneo unpub. data) and germinates readily following removal of the woody endocarp; however current work at Mount Annan Botanic Garden has not been able to produce consistent germination of intact fruit or extracted seed older than 9 months. Further research is required to determine the way fleshy fruit breaks down and dormancy is overcome, particularly under field conditions. Seed longevity in the soil seedbank is considered to be up to 2 years (von Richter, unpub. data), similar to other Oleaceae genera such as Privet (Panetta 2000). The role ingestion by birds plays in the breakdown of seed dormancy has not been assessed, but

Fig. 4a. The eastern side of Mount Annan in 1984 as a grazing property, with African Olive plants already well-established on the steeper slopes.

Fig. 4b. The same view in 2004, part of Mount Annan Botanic Garden since 1988, showing increased density and local expansion of African Olive plants. Recruitment of native eucalypts has taken place in the foreground where Olive has been controlled by spot herbicide application and mowing.

there appears to be a clear association between the spread of African Olive and dispersal of its seed by birds, and it is highly likely that removal of fleshy fruit through the bird digestive system assists germination.

Dispersal

Avian seed dispersal is a key characteristic of African Olive spread and establishment as an environmental weed. Birds are attracted to the fleshy black fruits, and seedlings establish under isolated trees used by birds (Benson & McDougall 1999). The fruits provide a nutritional source which could be considered comparable to that of the fleshy pulp of European Olive, which is high in oil content (5%–30%) (Levinson & Levinson 1984). In addition, the fruit is considered an important energy source for birds and small mammals (Spennemann & Allen 2000a). Introduced foxes (*Vulpes vulpes*) also consume significant amounts of African Olive fruits, with up to 142 olive seeds recorded from individual fox scats (L. von Richter unpub. data). Research on dispersal dynamics and establishment of African Olive seed is limited, however the pattern of dispersal where it establishes as seedling "halos" around large perch trees and along fence lines and powerlines is well documented (Spennemann & Allen 2000b, Muyt 2001, Starr 2003), indicating the importance of avian dispersors.

In dietary studies of Pied Currawongs near Sydney Buchanan (1989) found that plants from the Oleaceae family including African Olive and Privet species, *Ligustrum sinense* and *Ligustrum lucidum*, are the most significant part of their diet during the winter months. Long term bird banding studies in a heavy African Olive infestation at Mount Annan Botanic Garden have recorded both native and introduced birds feeding and voiding olive seeds. Native birds observed to eat/consume African Olive seeds at Mount Annan include Silvereye (*Zosterops lateralis*), Golden Whistler (*Pachycephala pectoralis*), Olive-backed Oriole (*Oriolus sagittatus*), Black-faced cuckoo shrike (*Coracina novaehollandiae*), Lewins honeyeater (*Meliphaga lewinii*), Pied Currawong (*Strepera graculina*), while introduced bird species include Red-whiskered Bulbul (*Pycnonotus jocosus*), Common Starling (*Sturnus vulgaris*) and Common Blackbird (*Turdus merula*) (Leishman, A. 2001). Though there is no quantitative data on the seed rain resulting from bird dispersal, Leishman, A. (2001) has recorded Silvereyes voiding up to 16 olive seeds, and a single Olive-backed Oriole voiding in excess of 30 olive seeds at Mount Annan during the holding time (30 minutes) prior to banding. On the Hawaiian Island of Maui, dispersal of African Olive seed by frugivorous birds and subsequent germination up to one mile from cultivated plants has been observed (Starr et al. 2003).

The role of birds in the seed dispersal and subsequent establishment of European olive as a weed is documented in Australia (Spennemann & Allen 2000b, Crossman 2002) and Spain (Alcantara et al. 1997). When cultivated olive groves are abandoned, the fruit of self-seeded olive trees are smaller than the original cultivars, and avian fruit dispersal increases (Spennemann & Allen 2000a) as birds are less able to manipulate and swallow fruits wider than 11.83 mm diameter (Alcantara & Rey 2003). The normal fruit size of ~7 mm for African Olive is well within the optimal size range for dispersal by a wide range of Australian native and introduced bird species. Large seeds are better able to tolerate a range of hazards during establishment than smaller seeds (Leishman et al. 2000), and the relatively large size of African Olive seed is likely to provide a competitive advantage (Leishman, MR 2001), particularly in grassy woodland communities such as in western Sydney, which are dominated by small-seeded herbaceous and graminoid species.

Typical stages of African Olive establishment and environmental impacts

Here we describe a model for African Olive establishment and spread based on observations and archives of African Olive populations at Mount Annan Botanic Garden and in bushland remnants across western Sydney over a 15 year period, and on aerial photo records (PWD 1985, Qasco 1993, Montgomery Watson 2000). Three distinct stages of invasion are recognised — initial invasion, establishment, and mature dense stand.

Initial invasion stage (0–7 years)

African Olive seed is dispersed by birds, and seedlings establish under isolated (or emergent) trees (Benson & McDougall 1999), forming seedling "halos". Some seedlings may establish following bird dispersal into understorey vegetation such as *Bursaria spinosa* thickets. Seedling growth rate is highly variable and dependent on aspect and moisture availability, with plants growing vigorously along creek and drainage lines. Plants in dry, open, exposed sites are commonly less than 1 m high after 5–10 years (D. Benson, pers. comm.). In moist, more protected sites, plants reach sexual maturity after 5–6 years and are commonly shrubs 3–4 m high and 3–4 m wide, with an average stem diameter of 35 mm at this early fruit-bearing age.

After shrubs begin fruiting they develop dense seedling "mats" in the seed fall zone of each plant. Seedling densities of 950 seedlings/m^2 are commonly observed, and seedlings in these dense 'mats' have the capacity to remain suppressed in this 'seedling bank' stage for many years. At the initial invasion stage, African Olive commonly occurs as scattered shrubs with light levels at ground level remaining high, and native shrubs such as *Bursaria spinosa* maintaining a comparable height and density to olives. Native grasses and herbs persist in the initial invasion stage, under the discontinuous olive/native shrub layer, and eucalypt seedling recruitment and sapling growth is still evident.

Establishment stage (8–12 years)

During the establishment stage, African Olive trees reach their full height of 10–13 m forming dense stands of slender single and multi-trunked trees with an average spacing of 1–2 m. Single trunked trees at this stage may have stem diameters averaging 100 mm (DBH), with multi-trunked trees averaging 158 mm. Light levels at the ground layer are now substantially reduced as the olive canopy begins to dominate and shade out native shrubs such as *Bursaria spinosa*. Recruitment of eucalypts is suppressed and olive seedling "mats" thin out to low density etiolated seedlings up to 1m high. Native plant species that favour edge conditions and higher light levels such as *Themeda australis, Austrodanthonia spp, Ajuga australis* and *Aristida vagans*, no longer persist under the increasing shade and root competition from the dense African Olive trees, though shade tolerant and resilient species such as *Dichondra repens, Microlaena stipoides, Brunoniella australis* and *Eremophila debilis* persist underneath olives at this stage. Eucalypt saplings and tall-growing species such as *Acacia implexa* that have maintained an adequate growth rate and height above the olive canopy continue to grow. A distinctive bare soil zone is evident along the margins of established

Table 3: Techniques and registered herbicides for the control of African Olive

Technique	Application/Method	Comments
Cut stump (cut & paint)	Plants are sawn off close to ground level and undiluted Glyphosate 360 g/l (eg,Roundup®) is applied (Ensbey 2004) by brush or applicator bottle (within 30 seconds) to the cambial layer of the stump (APVMA permit 9158). Triclopyr (Garlon 600® - reg label 31898) and diesel mixture (1:14) (Ensbey 2004) is also highly effective as a "cut and paint" application (Dellow 1987),	Plants growing in damp areas or treated during dry conditions may require special attention as they may re-shoot (National Trust 1999).
Foliar Spray	Spray control of seedlings and coppice shoots using Glyphosate 360g/l diluted at 1:75 or 1:100 rate (Ensbey 2004) (APVMA permit 9158).	Effectiveness is highly variable. Ziesing (1997) reports increased effectiveness in seedling control with the addition of Urea in spray tank.
Tree injection	Portable drills are used to drill 3 cm deep holes into the trunk at a 45 degree angle, spaced 4 cm apart. Undiluted Glyphosate 360 g/l at a rate of 2.5 ml per hole is injected into each hole using an applicator bottle or backpack injection unit (APVMA permit 9158). Frilling technique is similar, with chisels used instead of portable drills to create an opening at regular intervals in the trunk for the injection of glyphosate.	This is commonly used to control African Olive in inaccessible areas, such as olive "halos" around large Eucalypt perch trees, where cutting and removal of material is not practical. African Olives are left in situ and can be useful in maintaining temporary habitat for small native birds.
Basal bark spray	Garlon® (Triclopyr) diluted in diesel oil applied to the first 30 cm of trunk, wetting the bark to runoff point. In NSW & SA, Garlon® is registered for use on Olive as both a cut stump and basal bark application at a rate of 1:14 with diesel oil (Reg label 31898).	Simple-to-apply technique, outstanding in controlling olive regardless of size (Dellow 1987). Cost effective, but best done by experienced personnel with spray equipment fitted with Viton® seals (resistant to mineral oils). Care is required to prevent soil contamination in bushland areas.
Fire	Young olive plants <1 metre are killed by low intensity fire (von Richter et al 2005)	Mature African Olive trees can be controlled by fire when individual cut stumps are exposed to intense heat produced by large pile burns placed on top. (P. Dixon, pers. comm).
Physical removal/cultural	Seedlings can be hand pulled at the <10 cm stage, which is best done during moist soil conditions. African Olive is palatable to stock, who effectively control the development of young seedlings. In agricultural situations, African Olive is readily controlled by increasing grazing pressure (Parsons & Cuthbertson 1992).	
Mechanical removal	Mechanical control of mature plants with drum mulcher (attached to excavator) has been used where access is available and erosion hazard is low.	Highly effective for large scale infestations, provided African Olive trees and seedlings are treated with herbicide prior to mechanical mulching. Mulched material maintains soil cover.

stage African Olive stands, beyond the tree crown, but it is not known whether the development of a dense African Olive crown has an allelopathic effect on native species, similar to that described for weedy European Olives in Australia (Plant & Animal Control Commission 2006).

Mature dense stand stage (15 years +)

As African Olive establishes mature dense stands over 15 years or longer, the vegetation structure changes towards a more uniform stand dominated by multi-trunked trees with an open understorey. Individual trees are large and commonly multi-trunked close to ground level, with an average diameter (DBH) of 338 mm. The crowns of these mature trees are dense and spreading, forming a continuous canopy 15–18 m high. Only older emergent Eucalypts are able to survive above the African Olive canopy. At this stage African Olives have an average spacing of 6–8 m, with light levels at the ground level now sufficiently low that olive seedlings are suppressed. Most native seedlings are suppressed under the dense canopy, with only highly shade tolerant species such as Maidenhair fern, *Adiantum aethiopicum*, and the climber, *Cayratia clematidea,* persisting under the dense canopy. The margins of mature dense stands receive higher light levels and are occupied by smaller, densely-branched Olives averaging 5 m in height, with dense seedling 'mats' of Olive seedlings.

Fire response

African Olive regenerates readily from a lignotuber structure at the base of the trunk after fire, in a similar manner to the native shrub *Bursaria spinosa* with which it commonly co-occurs in the Sydney region. African Olive seedlings up to 1 m high are killed by low intensity fire (von Richter et al. 2005).

Environmental conditions and impacts

African Olive appears to tolerate a wide range of environmental conditions and is able to establish in temperate or subtropical environments. African Olive is able to establish on steep, exposed hilly terrain well beyond the tolerance of related woody weeds such as Privet (*Ligustrum* spp). The southern Cumberland Plain is an area of low rainfall in the Sydney Basin (Camden – 828 mm, Bureau of Meteorology 2006), and African Olive has successfully established in most plant communities and aspects in this undulating, hilly terrain.

The high resin content of leaves and stems is a contributing factor to its ability to withstand the climatic extremes of exposed, west-facing slopes and ridgelines on poorly-developed soils. On the southern Cumberland Plain, African Olive shows a strong preference for clay-based soils derived from Wianamatta Shale, with seedling and mature plant establishment in adjacent Hawkesbury Sandstone areas only sporadically observed around perch trees. The large seed size of African Olive suggests that it can tolerate a broad range of establishment hazards such as shade, low soil moisture, herbivory and competition. Cooke (2001) showed that soil beneath African Olive canopy had elevated pH and available phosphorus, but not to the extent of Privet (*Ligustrum* spp) which was associated with phosphorus levels five times that of soil associated with native vegetation.

The establishment of African Olive along roadsides and exclusion of native species has a significant impact on native plant diversity, as roadsides are often the last refuge for understorey species that have been lost through grazing and clearing of adjacent properties. The establishment of African Olive to the mature canopy stage permanently changes ecological function and landscape identity by dramatically reducing native plant diversity.

Noxious weed declarations and control techniques

African Olive is currently a declared Class 4 noxious weed under section 7 of the NSW Noxious Weeds Act 1993 for the Ryde LGA. The control objective for class 4 weeds is to minimise the negative impact of those plants on the economy, community or environment of NSW (NSW Government 2005). As a Class 4 weed in the Ryde LGA, the growth and spread of African Olive must be controlled according to the measures specified in a management plan published by the local control authority and the plant may not be sold, propagated or knowingly distributed (NSW DPI 2006). In view of the current African Olive infestation and spread in regions such as western Sydney there is clearly a need for a review of its declaration as a noxious weed beyond the Ryde LGA. The recent declaration of Privet (*Ligustrum lucidum* and *L.sinense*) as a Class 4 weed in seven western Sydney LGAs presents an opportunity for the co-management of both Privet species and African Olive in the development of Class 4 weed management plans.

In South Australia, Olive (all subspecies of *Olea europaea*) are listed as a Class 5d weed under the Natural Resources Management Act 2004. Under the provisions of this Act, an owner of land within a control area for a class of plants to which this subsection applies must control and keep controlled all plants of that class on that land (Parliament of South Australia 2004). For Class 5d weeds, landowners may also be liable for the cost of roadside weed control measures adjacent to their property.

There are no known biological control agents used in the control of African Olive in Australia. Olive Lace Bug (*Frogattia olivinia*) is native to NSW and southern Queensland and has potential as a biological control agent for weedy *Olea* species. Olive Lace Bug is known as a pest of European Olive (WA Agriculture 2004) and has established widely on weedy European olives in South Australia, causing small olive fruits on heavily infected trees to fall before ripening (Robertson 2005). Olive Lace Bug has not been

noted as impacting on African Olive, and research is required to determine if it could provide a level of biological control. With the rapid growth of the olive industry in Australia in recent decades, any move to introduce a biological control agent for African Olive is likely to encounter strong industry resistance.

Conclusions and recommendations

African Olive is a highly persistent and adaptable environmental weed now well-established in eastern Australia. Although part of the *Olea europaea* complex, African Olive is part of a tropical wild olive group, and has a weed ecology that is distinct from European Olive. Distributional data show that African Olive has been able to invade a wide range of habitats ranging from temperate regions with about 800 mm rainfall through to subtropical zones which receive 1200 mm annual rainfall. Its rate of spread in south-western Sydney and the Hunter Valley clearly indicate that this species can no longer be considered a 'sleeper' weed. In the Sydney region, African Olive has the ability to establish on dry exposed ridgelines, yet is also able to grow in conjunction with other woody weeds in the *Oleaceae* such as Privet (*Ligustrum spp*), on high soil moisture and fertility sites.

African Olive invasion leads to a loss in native plant diversity, and research into restoration ecology is needed, particularly for sites with an established cover of African Olive where bush regeneration, and cutting and poisoning are the main methods of control. There is a need for further research into the persistence of African Olive seed in the soil seedbank, and the process by which seed dormancy is overcome. As avian dispersal is a key factor in African Olive seed dispersal, the role of frugivorous birds in promoting seed germination needs to be further understood. Key aspects of restoration ecology would include an investigation of an apparent allelopathic effect observed under dense olive stands, the role of shade in suppressing other plant species, and the use of fire to kill immature plants and stimulate the native soil seed bank.

At the landscape scale, the current distribution of African Olive in eastern Australia should be accurately mapped, and a weed awareness strategy developed and implemented across affected local government areas. GIS and satellite imagery offer the potential to complete coarse scale mapping based on the distinctive reflectivity and texture of African Olive. Modelling of potential for African Olive spread should also be undertaken, based on current distributional data and habitat preference.

There is a strong case for African Olive to be declared a noxious weed throughout western Sydney and the Hunter Valley regions, and co-managed with Privet (*Ligustrum* spp) under Class 4 weed control plans. A re-evaluation of the most effective control techniques, including currently registered herbicides, is also required.

Fig. 5. Dense seedling 'mats' form in the seed-fall zone around mature African Olive plants – providing a 'seedling bank' for future recruitment.

Fig. 6. Birds deposit the woody seed endocarp under perch trees - providing a source point for African Olive infestation.

Fig. 7. Mature African Olive resprouting 18 months after fire; seedlings and young plants less than about a metre high are generally killed by fire.

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