

The naturalised vascular plants of the Pilbara region, Western Australia

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Abstract – Populations of 103 weeds are currently established in the Pilbara, comprising 6.3% of the region's flora; 19 are here newly recorded since the previous listing in 2004. Most originated in tropical Africa, America or Asia and were introduced intentionally as garden, amenity or fodder plants. Most are annual or perennial herbs with small seeds usually dispersed in soil, machinery, wind and water. Fourteen species affect the region at a landscape scale by altering fire patterns, modifying soil characteristics or competing directly with native species. Another 15 species significantly modify particular habitats such as wetlands, 6 are major threats to islands and a further 16 have potential threat to Pilbara environments.

INTRODUCTION

Since European settlement, exotic plant species (weeds) have become naturalised in Australia at the rate of about 7 to 11 species per year (Csurshes and Edwards 1998). Currently, 2739 species are naturalised in Australia (Randall 2007), which is about 19% of the flora. Even so, with a short history of European settlement, Australia is still comparatively free of weeds when compared to countries such as Britain with 32% and New Zealand with 51% of their floras naturalised exotics (Storrs and Lonsdale 1995).

Despite being recognised as a major threat to biodiversity, the naturalised vascular flora of Western Australia is still poorly documented. Approximately 1234 taxa are known, 12% of the State's total flora (Keighery and Longman 2004). The majority of these are found in the intensive land-use zone of southern Western Australia. Because of limited agricultural use, low population densities, seasonal aridity and low soil fertility, Australia's tropical regions have lower percentages of weeds. Keighery and Longman (2004) listed 86 naturalised weeds from the Pilbara bioregion (5.7% of the total Pilbara flora), 135 (8%) from the adjacent Carnarvon bioregion and 120 (8.6%) from Dampierland bioregion. These figures are comparable to the Northern Territory, which has 237 species of exotics, representing 5.6% of its flora, the lowest percentage of any Australian State or Territory.

There are two key publications on Pilbara weeds—a checklist provided in Keighery and Longman (2004) and a list for the region's pastoral lands in Van Vreeswyk *et al.* (2004). This paper combines and revises these lists, includes the

results of field survey work carried out as part of a wider biodiversity survey of the Pilbara bioregion (McKenzie *et al.* 2009), and provides a fuller inventory and appraisal of the conservation implications of naturalised plants in the Pilbara.

METHODS

Preparing an inventory of weeds for the Pilbara required survey methods different from those used in the elucidation of patterns in the native biota. The sample sites for the biodiversity survey were positioned in relatively undisturbed areas (McKenzie *et al.* 2009) and consequently sampled only weeds present at a landscape scale. The key sources for the present weed inventory were herbarium searches in combination with targeted field surveys. Records at the National Herbarium of Victoria, Melbourne, and the Western Australian Herbarium, Perth, were consulted, along with data from FloraBase (Western Australian Herbarium 1998–) and Australia's Virtual Herbarium (Australia's Virtual Herbarium 2010). Papers and reports of other recent fieldwork and taxonomic studies were also consulted. This information was supplemented by records from the Pilbara Biodiversity Survey's sample sites as well as by opportunistic records and collections made while traversing the region during this study. A specific survey was undertaken in 2006/7 to record and voucher weeds established around settlements. These are the most disturbed sites, the places where many plants first escape from cultivation. Ten new weeds for the Pilbara were located in these sites.

Accounts by explorers (Gregory and Gregory 1884), historians (Gordon 2004) and botanists (Mueller 1886) were consulted to obtain a historical

context on the region's weeds.

Information from the above sources and other sources (see below) was used to determine, for each weed taxon, the reason the taxon was introduced and the habitats that each has affected. Further information was derived from workshops for ranking environmental weeds for the Department of Environment and Conservation (DEC) Pilbara Region, part of a Statewide program by Nature Conservation Division and DEC Science to rank weeds.

RESULTS AND DISCUSSION

The fieldwork and reviews yielded a list of 103 naturalised plants for the Pilbara, information on the reason each taxon was introduced and the main environments in which it has been found (Table 1). In comparison, 86 taxa were listed by Keighery and Longman (2004) and 44 by Van Vreeswyk (2004).

Weedy status and early records

The first unequivocal record of a weed from the region was a collection by J. Sewell from Nickol Bay in 1885. This was described as a new genus and species of lily, *Elachanthera sewelliae*, by Mueller (1886) but is, in fact, the weed *Asparagus asparagoides* (Bridal Creeper). This species was commonly cultivated in colonial homestead gardens but has not been recorded in the Pilbara since that date.

The Australian tropics are rich in pan-tropical or cosmopolitan weedy 'tramp' species. The native or naturalised status of these taxa is often queried and it is difficult to establish their status. These taxa are often treated as weeds in floras and in more general weed lists, and the exclusion of some of these from Table 1 requires justification. Eight species assigned to this category by Groves *et al.* (2003) are present in the Pilbara: *Vachellia farnesiana*, *Phyla nodiflora*, *Helichrysum luteoalbum*, *Albizzia lebbek*, *Bidens pilosa*, *Echinochloa colona*, *Salsola kali* and *Persicaria lapathifolia*. These taxa were most likely introduced before European settlement by Macassan fishermen from Indonesia or by birds from south-eastern Asia (Bean 2007).

The first weed records from the Pilbara were some of these cosmopolitan weedy species. *Vachellia farnesiana* was collected at Nickol Bay by the Gregory expedition in 1861, before the establishment of any settlements. Kodela and Tindale (2001) believe this is a pre-European introduction from Central America via the Philippines. Similarly, *Phyla nodiflora* was collected on the Fortescue River by J.W. Cussack in 1895 and, though the status of this species is still uncertain, it is also currently regarded as a pre-European introduction.

Helichrysum luteoalbum, collected by Alexander

Forrest on the Yule, Ashburton and Cane Rivers in 1879 (although labelled as 1870 on the collections) is currently considered either a weed or native, depending on which State or list one is following. While this species, *Vachellia farnesiana* and *Phyla nodiflora* are retained as weeds in Table 1, their status may be changed in the future.

In this paper *Albizzia lebbek* is considered native to the Kimberley but introduced to the Pilbara (Hussey *et al.* 2007). *Bidens pilosa* and *Echinochloa colona* are now considered to have been introduced to Australia (Bean 2007). In contrast, Australian plants previously called *Salsola kali* and considered a weed, have been shown by Borger *et al.* (2008) and Borger and Scott (2009) to be a native species (*Salsola australis*), so it is not listed in this paper. Similarly *Flaveria*, recorded as either *F. australasica* or *F. trimeria*, is considered indigenous to Australia, having been first collected in 1802 and considered a separate taxon by Powell (1978) in his generic revision.

Persicaria lapathifolia was recorded for the Pilbara by Van Vreeswyk (2004). However, Karen Wilson (National Herbarium of New South Wales) re-determined the voucher of this record as *Persicaria ?glabra* (Willd.) M. Gomez, a weed that has not previously been recorded from Western Australia. I have re-examined all *Persicaria* collections from the Kimberley and Pilbara in the Western Australian Herbarium and re-determined these as an intermediate taxon that has been temporarily labelled as *Persicaria glabra* × *lapathifolia*. This taxon, while not referable to a known species, is apparently a native, and will be listed as such by FloraBase. Hence, *Persicaria lapathifolia* is not listed in this paper.

Some plants have been shown to consist of both native and introduced populations in the Pilbara. Morrison and Scott (1996a, b) and Scott and Morrison (1996) have shown that *Tribulus terrestris* is a complex of native and introduced taxa. Most Pilbara records are probably the native *T. eichlerianus*, but the weedy *T. terrestris* is found around towns so this species is retained in the list. Records of *Oxalis corniculata* from the Hamersley Range have been re-determined as an un-named native species (*Oxalis* sp. Pilbara M.E. Trudgen 12275), although the weed is still present in townsites in the region (Keighery and Keighery 2008).

Similarly, *Portulaca oleracea*, considered by Bean (2007) to be introduced, has long been regarded as comprising native and introduced populations (Gardner 1925) in Western Australia, a view supported by a world-wide revision of the species (Danin *et al.* 1978) that noted 'In Australia there is a high diversity of forms which differ from those in all other parts of the world', and 'Most

Table 1 Naturalised taxa (weeds) recorded for the Pilbara, listed against the purpose of introduction, the habitats each has affected and earliest records.

FAMILY/Taxon	Purpose of introduction	Habitats affected	Earliest record (H: herbarium record; L: literature record)
AGAVACEAE <i>Agave americana</i> L.	ornamental	urban (current and old settlements)	2006 (H); new record
AIZOACEAE <i>Trianthema portulacastrum</i> L.	unknown	disturbed, grazed coastal, alluvium, loam	1941 (H)
AMARANTHACEAE <i>Aerva javanica</i> (Burm f.) Juss. ex Schult. <i>Amaranthus viridis</i> L. <i>Alternanthera pungens</i> Kunth. <i>Gomphrena celosioides</i> Mart. <i>Pupalia lappacea</i> (L.) Juss	ornamental, rehabilitation, fodder food, fodder fodder unknown unknown	coastal dunes, limestone, sand urban ruderal, highly disturbed sites ruderal, urban, creeklines coastal	1920 (L) 1947 (H) 1920 (L) 1973 (H) 1950 (H)
APIACEAE <i>Cyclospermum leptophyllum</i> (Pers.) Brittan & P.Wilson	fodder, ?unknown	urban (lawns)	2004 (H); new record
APOCYNACEAE <i>Asclepias curassavica</i> L. <i>Calotropis procera</i> (Aiton) W. Aiton <i>Catharanthus roseus</i> (L.) G.Don	ornamental ornamental ornamental	urban alluvium ruderal, urban, creeklines	1986 (H) 2004 (L) 1962 (H)
ALOEACEAE <i>Aloe vera</i> (L.) Burm.f. var. <i>officinalis</i> (Forrsk.) Baker	herbal, ornamental	urban (old settlements)	2004 (H); new record
ARECACEAE <i>Phoenix dactylifera</i> L. <i>Washingtonia filifera</i> H.Wendl <i>Washingtonia robusta</i> H.Wendl.	shade, ornamental shade, ornamental shade, ornamental	riverine riverine riverine	1890 (L), 1984 (H) 1890 (L), 1990 (H) 2004 (H); new record
ASPARAGACEAE <i>Asparagus asparagoides</i> (L.) Druce	ornamental	unknown	1895 (H)
ASPHODELACEAE <i>Asphodelus fistulosus</i> L.	accidental	alluvium	1979 (H)
ASTERACEAE <i>Bidens bipinnata</i> L. <i>Bidens pilosa</i> L. <i>Conyza bonariensis</i> (L.) Cronquist <i>Helichrysum luteoalbum</i> L. <i>Lactuca saligna</i> L.	unknown unknown, ?ornamental accidental unknown fodder, ?food	grazed woodlands (especially Mulga), creeklines, alluvium as previous urban riverine, wetland margins, disturbed areas urban	1962 (H) 1984 (H) 2001 (H) 1879 (H) 2004 (H); new record

FAMILY/Taxon	Purpose of introduction	Habitats affected	Earliest record (H: herbarium record; L: literature record)
ASTERACEAE (continued)			
<i>Lactuca serriola</i> L.	fodder, ?food	urban	2000 (H)
<i>Sigesbeckia orientalis</i> L.	unknown	wetlands	1960 (H)
<i>Solidago canadensis</i> L.	ornamental	urban	1996 (H)
<i>Sonchus oleraceus</i> L.	accidental	wetlands	1971 (H)
<i>Taraxacum officinale</i> F.H.Wigg.	accidental	urban	2006 (H); new record
<i>Wedelia trilobata</i> (L.) Hitchc.	ornamental	wetlands	2006 (H); new record
BIGNONIACEAE			
<i>Tecoma stans</i> (L.) Kunth	ornamental	urban areas	2006 (H); new record
BRASSICACEAE			
<i>Brassica napus</i> L.	seed	ruderal, creeklines	2005 (H); new record
<i>Brassica tournefortii</i> L.	contaminant	islands, coastal dunes	2006 (H); new record
<i>Sisymbrium orientale</i> L.	contaminant	ruderal, urban, islands	1996 (H)
CACTACEAE			
<i>Opuntia stricta</i> (Haw.) Haw.	ornamental, edible fruit	islands, coastal sites	1924 (H)
CHENOPODIACEAE			
<i>Chenopodium murale</i> L.	salad green	urban, wetlands	1969 (H)
CONVOLVULACEAE			
<i>Merremia dissecta</i> (Jacq.) Hallier f.	ornamental	wetlands	1962 (H)
CUCURBITACEAE			
<i>Citrullus colocynthis</i> (L.) Schrud.	fruit	ruderal, highly disturbed sites	1978 (H)
<i>Citrullus lanatus</i> (Thunb.) Matsum. & Nakai	fruit	ruderal, highly disturbed sites	1987 (H)
<i>Cucumis melo</i> subsp. <i>agrestis</i> (Naudin) Pangalo	fruit	ruderal, highly disturbed sites, creeklines	1937 (H)
<i>Cucumis myriocarpus</i> Naudin	fruit	ruderal, highly disturbed sites	2001 (H)
CYPERACEAE			
<i>Cyperus involucratus</i> Poir.	ornamental	wetlands	2006 (H); new record
<i>Cyperus polystachyos</i> Rottb.	unknown	wetlands	1996 (H)
<i>Cyperus rotundus</i> L.	unknown, ?food	wetlands	1976 (H)
EUPHORBIACEAE			
<i>Euphorbia hirta</i> L.	contaminant	urban, ruderal	2006 (H); new record
<i>Jatropha gossypifolia</i> L.	ornamental	grazed rangelands	1980 (H)
<i>Phyllanthus tenellus</i> Roxb.	contaminant	urban (gardens)	2006 (H); new record
<i>Ricinus communis</i> L.	ornamental	riverine	1995 (H)
FABACEAE			
<i>Albizia lebbek</i> (L.) Benth.	shade tree	riverine	1890 (L), 1935 (H)
<i>Clitoria ternatea</i> L.	ornamental	wetlands, riverine	1969 (H)
<i>Crotalaria juncea</i> L.	fodder	grazed rangelands	1995 (H)
<i>Desmodium scorpiurus</i> (Sw.) Desv.	fodder	grazed rangelands	1962 (H)
<i>Indigofera oblongifolia</i> Forssk.	fodder	alluvium, riverine and black soils	1982 (H)

FAMILY/Taxon	Purpose of introduction	Habitats affected	Earliest record (H: herbarium record; L: literature record)
FABACEAE (continued)			
<i>Indigofera sessiliflora</i> DC.	fodder contaminant	grazed rangelands	1991 (H)
<i>Leucaena leucocephala</i> (Lam.) de Wit	shade tree, fodder	riverine, wetlands, alluvium	1996 (H)
<i>Medicago polymorpha</i> L.	fodder	southern coastal dunes and ranges	2006 (H); new record
<i>Parkinsonia aculeata</i> L.	shade	riverine, alluvium	1951 (H)
<i>Prosopis glandulosa</i> × <i>velutina</i> Torr. & Wooton	ornamental	riverine, alluvium	1930 (L), 1984 (H)
<i>Prosopis pallida</i> (Willd.) Kunth	ornamental	riverine, alluvium	1930 (L), 1936 (H)
<i>Senna occidentalis</i> (L.) Link	unknown	riverine, alluvium	1975 (H)
<i>Stylosanthes guianensis</i> (Aubl.) Sw.	fodder	grazed rangelands	1953 (H)
<i>Stylosanthes hamata</i> (L.) Taub	fodder	grazed rangelands	1997 (H)
<i>Tamarindus indica</i> L.	shade tree, fruit	urban	1932 (H)
<i>Vachellia farnesiana</i> (L.) Wight & Arn.	unknown	many habitats, especially alluvium, grazed rangelands	1861 (H)
MALVACEAE			
<i>Gossypium hirsutum</i> L.	seeds, ornamental	urban	1996 (H)
<i>Malvastrum americanum</i> (L.) Torr.	unknown	many habitats	1938 (H)
<i>Malvastrum coromandelianum</i> (L.) Garcke	unknown	many habitats	1982 (H)
<i>Melochia pyramidata</i> L.	unknown	many habitats, especially alluvium	1931 (H)
MORINGACEAE			
<i>Moringa oleifolia</i> Lam.	ornamental	creeklines	1973 (H)
NYMPHAEACEAE			
<i>Nymphaea macrosperma</i> Merr. & L.Perry	ornamental	riverine pools	1890 (L), 1958 (H)
OXALIDACEAE			
<i>Oxalis corniculata</i> L.	lawn weed	urban	2006 (H); new record
PAPAVERACEAE			
<i>Argemone ochroleuca</i> Sweet subsp. <i>ochroleuca</i>	ornamental	riverine, alluvium	1916 (H)
PASSIFLORACEAE			
<i>Passiflora foetida</i> var. <i>hispida</i> (Triana et Planch.) Killip	unknown	coastal dunes, islands, rocky sites, riverine	1946 (H)
POACEAE			
<i>Andropogon gayanus</i> Kunth	fodder	riverine, alluvium	1953 (H)
<i>Arundo donax</i> L.	ornamental	riverine	1890 (L), 1996 (H)
<i>Avena barbata</i> L.	fodder	southern coastal dunes, islands	2006 (H); new record
<i>Cenchrus ciliaris</i> L.	fodder	many habitats, especially coastal dunes	1900 (L), 1922 (H)
<i>Cenchrus echinatus</i> L.	fodder	riverine, alluvium	1900 (L), 1983 (H)

FAMILY/Taxon	Purpose of introduction	Habitats affected	Earliest record (H: herbarium record; L: literature record)
POACEAE (continued)			
<i>Cenchrus setiger</i> Vahl.	fodder	riverine, alluvium, ruderal	1900 (L), 1929 (H)
<i>Chloris barbata</i> Sw.	unknown	riverine, alluvium, ruderal	1979 (H)
<i>Chloris virgata</i> Sw.	fodder	riverine, alluvium, ruderal	1953 (H)
<i>Cynodon dactylon</i> (L.) Pers.	ornamental	wetlands, urban	1941 (H)
<i>Dichanthium annulatum</i> (Forrsk.) Stapf	fodder	wetlands	2001 (H)
<i>Digitaria ciliaris</i> (Retz.) Koeler	?fodder, contaminant	riverine, alluvium, ruderal	1992 (H)
<i>Echinochloa colona</i> (L.) Link	fodder, ?birdseed	wetlands	1941 (H)
<i>Eragrostis minor</i> Host.	?fodder, contaminant	ruderal	1988 (H)
<i>Eragrostis pilosa</i> (L.) Beauv.	?fodder, contaminant	ruderal	2002 (H)
<i>Lamarckia aurea</i> (L.) Moench	ornamental, fodder	alluvium	1953 (H)
<i>Leptochloa fusca</i> subsp. <i>uninervia</i> (J.Presl) N.Snow	fodder, rehabilitation	wetlands, alluvium	1958 (H)
<i>Melinis repens</i> (Willd.) Zizka	ornamental, fodder	ruderal, rangelands	2006 (H); new record
<i>Paspalum fasciculatum</i> Fluegge	fodder	wetlands	1953 (H)
<i>Pennisetum setaceum</i> (Forrsk.) Chiov	ornamental	coastal dunes, southern rangelands	1953 (H)
<i>Polypogon monspeliensis</i> (L.) Desv.	fodder	fresh and brackish wetlands	1995 (H)
<i>Setaria italica</i> (L.) P.Beauv.	bird seed, fodder	?localised, urban	1898 (H)
<i>Setaria sphacelata</i> (Schumach.) Stapf. & C.E.Hubb.	fodder	?localised, urban	1953 (H)
<i>Setaria verticillata</i> (L.) P.Beauv.	fodder	?localised, urban	1937 (H)
POLYGONACEAE			
<i>Acetosa vesicaria</i> (L.) A.Love	ornamental, rehabilitation	potentially widespread on alluvium, clay and loam soils	1971 (H)
PORTULACACEAE			
<i>Portulaca oleracea</i> L.	unknown (native and weed)	urban, ruderal	2006 (H); new record
PTERIDIACEAE			
<i>Ceratopteris thalictroides</i> (L.) Brongn.	ornamental	riverine, river pools	1890 (L), 1932 (H)
SALVINIACEAE			
<i>Salvinia molesta</i> D.S.Mitch.	ornamental	riverine, river pools	1986 (H)
SOLANACEAE			
<i>Datura leichhardtii</i> Benth.	unknown	creeklines	1941 (H)
<i>Datura metel</i> L.	ornamental	urban	1988 (H)
<i>Physalis angulata</i> L.	fruit, unknown	creeklines	1995 (H)
<i>Solanum nigrum</i> L.	fruit	urban, wetlands, riverine	1997 (H)
TAMARICACEAE			
<i>Tamarix aphylla</i> L.	shade	riverine	2006 (H); new record
VERBENACEAE			
<i>Phyla nodiflora</i> (L.) Greene var. <i>nodiflora</i>	ornamental, lawns	alluvium, riverine	1895 (H)
ZYGOPHYLLACEAE			
<i>Tribulus terrestris</i> L.	unknown/contaminant	ruderal, grazed rangelands	1991 (H)

specimens that we have seen from different parts of Australia and New Zealand do not agree with our description of the subspecies from other parts of the world'. Populations collected in 2006 in towns and along roadsides in the Pilbara correspond to the inbreeding, small-flowered weedy bio-type of southern Western Australia.

Taxonomic re-arrangements have changed or removed other records. *Sonchus asper* was recorded for the Pilbara by Van Vreeswyk (2004) but, at that time, the specimens identified as this species included the native *Sonchus hydrophilus*. All Pilbara records are the native species. The record of *Digitaria sanguinalis* in Van Vreeswyk (2004) is now considered to be *D. ciliaris*. The record of *Zizyphus mauritiana* in Van Vreeswyk (2004) is from Onslow, which is outside the Pilbara. Conversely, *Calotropis procera*, recorded by Longbottom (2004) as established along the De Grey River system, is not recorded elsewhere in the Pilbara. This species is highly invasive of black soil plains in Western Australia and the Northern Territory and is being actively controlled in the Pilbara.

A number of introduced species are not considered to have become naturalised in the Pilbara. These include non-persistent species of refuse sites. Just after the wet season, we recorded vigorous stands of many cucurbit vines along rivers adjacent to the North West Coastal Highway. The stands had sprouted from material buried by visitors during the previous dry season and included *Cucumis sativus* L. (Cucumber) (G. Keighery 17365) from India; *Cucurbita pepo* (L.) Dumort. (Squash) (G. Keighery 17362) from Africa; *Cucumis melo* L. subsp. *melo* (Melon) (G. Keighery 17364) from America; *Curcubita maxima* Duschene ex Lam. (Pumpkin) (G. Keighery 17363) from South America; and *Citrillus lanatus* var. *vulgaris* (Schrad.) Fursa (Watermelon) (G. Keighery 17366) from Africa. It is unlikely that these annuals would re-seed and they should be regarded as having established temporary populations in the region.

Suckering stands of Bougainvillea (*Bougainvillea glabra* Choisy) were also recorded as long-persistent plants on several abandoned stations, but these are not naturalised. A stand of the cactus *Hylocereus undulatus* (Haw.) Brittan & Rose (Night-blooming Cereus) was recorded on the rubbish tip at Cane River Station but has been eradicated.

At workshops held in 2009 to prioritise environmental weeds in the Pilbara, ten weeds in mainly urban situations were noted that require collections for determination before being added to the Pilbara weed list:

- *Cardiospermum halicacabum* L. var. *halicacabum* (Sapindaceae), Small Balloon Creeper Vine, Karratha gardens;

- *Euphorbia tirucalli* L. (Euphorbiaceae), Finger Tree or Naked Lady, eradicated from Pippingarra Station;
- *Nerium oleander* L. (Apocynaceae), Oleander, Dampier gardens;
- *Celosia argentea* L. (Amaranthaceae), Cockscomb, Karratha gardens;
- *Ipomoea quamoclit* L. (Convolvulaceae), Cupid's Flower, Port Hedland;
- *Crotalaria juncea* L. (Fabaceae), Sun Hemp, Port Hedland;
- *Gnaphalium polycaulon* Pers. (Asteraceae), Western Cudweed, Karratha;
- *Cenchrus incertus* M.A. Curtis (Poaceae), Spiny Burrgrass, Port Hedland.

Participants reported that either *Paspalum distichum* L. (Poaceae) or *P. vaginatum* Sw., both known as Saltwater Couch, is present in wetlands in the Pilbara.

There are also weeds noted in consultancy reports that are not supported by voucher collections in the Western Australian Herbarium, or that are listed rarely or listed as eradicated:

- *Bassia scoparia* L. (Chenopodiaceae), Kochia, has been recorded from Marandoo (although it was in the nursery) in Matiske (1992). Biota (2009) again listed this species, but its present status is unknown.
- *Cenchrus biflorus* Roxb. (Poaceae), Gallon's Curse, was recorded at Millstream, subsequently eradicated. However, sight records by S. van Leeuwen indicate that this species is still being introduced into the Pilbara on vehicles.
- *Chloris gayana* Kunth (Poaceae), Rhodes Grass, was growing in rehabilitation areas and along creek lines in the Shay Gap/Yarrie area (Strategen 2006, BHP 2009). However, sight records by S. van Leeuwen around Karratha and Tom Price, indicate that this species is also still being introduced into the Pilbara on vehicles.
- *Emex australis* Steinh. (Polygonaceae), Doublegee, was recorded at Yandicoogina by Matiske (1995).
- *Euphorbia peplus* L. (Euphorbiaceae), Petty Spurge, has been recorded from Marandoo (Biota 2009).
- *Lawsonia inermis* L. (Lythraceae), Henna, was recorded around Dampier by V. Long (pers. comm.).
- *Ocimum basilicum* L. (Lamiaceae), Sweet Basil, was recorded from a creekline east of the Bungaroo Road (Biota 2006).
- *Sisymbrium irio* L. (Brassicaceae), London Rocket,

was recorded in Marillana Creek (Biota 2004).

- *Vitex trifolia* var. *subtrisecta* (Kuntze) Mold. (Lamiaceae), Beach Vitex, was recorded growing in disturbed coastal dune habitat at Cape Lambert (Biota 2008).
- *Vinca major* L. (Apocynaceae), Blue Periwinkle, recorded from a creekline east of the Mesa A transport corridor (Biota 2006).

Finally, neither *Borassus* sp. (Borassus Palm), which has been eradicated, nor *Helianthus annuus* L. (Sunflower) appears in Table 1. Sporadic sightings of individual plants of *H. annuus* have been made near Pannawonica and Dampier, but this species may eventually become established in the southern coastal areas of the Pilbara. Of those taxa not yet definitely recorded as weeds in the region, it would appear that three—*Chloris gayana*, *Cenchrus biflorus* and *Vitex trifolia* var. *subtrisecta*—have the potential become naturalised members of the flora of the Pilbara.

History of introductions

European settlement started in the Pilbara in 1863 with the establishment of the first pastoral lease, De Grey Station, followed by Cossack port and Roebourne townsite in 1864 (Withnell 1936). No doubt plants were introduced from this time, since many early publications and photographs show established kitchen and ornamental gardens at pastoral homesteads.

A good example of this process is from Millstream Station (21°35'25"S, 117°04'05"E), first selected in 1864 by Alex McRae and Trevor McKenzie. It was operated by them until 1879 when the lease was purchased by Walter Padbury and William Loton (Withnell Taylor 2002) who ran it until 1914. Numerous exotic species were introduced around the homestead and along the river to add shade and beautification. From photographs illustrated in Gordon (2004, p. 73), these included Tamarisk (*Tamarix aphylla*) and Albizia (*Albizia lebbek*). Cotton Palm (*Washingtonia filifera*), Date Palm (*Phoenix dactylifera*), Bamboo (*Arundo donax*), Borassus Palm (*Borassus aethiopica*?), Yellow Oleander (*Thevetia peruviana*) and Oleander (*Nerium oleander*) were planted along the Fortescue River. Several ornamental aquatics, including Waterlily (*Nymphaea macrosperma*) and the Indian Water Fern (*Ceratopteris thalictroides*), were planted in Chinderwarriner Pool adjacent to the homestead.

By 2007, many of these had disappeared, and only a single Borassus Palm remained (Anon. 2007), which has since been removed. However, the Date Palm, Cotton Palm, Waterlily and Indian Water Fern have become major local weeds. The first herbarium record of the Water Fern dates from a collection made at Millstream (21°35'25"S,

117°04'05"E) by Charles Gardner in August 1932, and the first Waterlily specimen was collected by K. Vollprecht from Crystal Pool (21°35'23"S, 117°03'59"E) between 1958 and 1960. The Palms, being rather difficult to process as herbarium material, were not collected until much later: Date Palm by Alex George in March 1962, and Cotton Palm by Estelle Leyland in July 1990. This illustrates a gap of up to 100 years between introduction or establishment and herbarium documentation.

Table 1 lists the mode of entry into Australia of the weeds recorded for the Pilbara. A series of introduction categories (Lazarides *et al.* 1997) predominate:

- 39 taxa for fodder or food;
- 36 taxa as ornamental garden plants; and
- 7 accidental.

The origins of introduction of 22 taxa are unknown.

The figures show that most taxa (over 70%) were deliberately introduced for horticulture or agriculture, a proportion that is typical for weeds in general. However, the timing, causes and methods of introduction to the Pilbara were often different from the original reasons for introduction and are difficult to establish. For example, Buffel Grass (*Cenchrus ciliaris*) was noted by Hennig (2004) to have been introduced to the Port Hedland area in the saddle padding for Afghan camels in the 1920s. It then became established on the town common and was subsequently spread as a pasture species. However, it is understood that this species was introduced into Australia elsewhere as a pasture species. Other authors also refer to different reasons for its introduction to the Pilbara. For example Van Vreeswyk (2004) noted that Buffel Grass was introduced by pastoralists to the delta of the Yule River in the early 1900s. Petheram and Kok (1983) noted that *Aerva javanica* and *Calotropis procera* were also used as padding in camel saddles and were introduced to the Pilbara in a similar manner, a statement supported by the earliest collection of *Aerva* from the Pilbara in 1920. *Aerva javanica* was subsequently used widely for revegetation in the Ord and Fitzroy basins. At the same time, Birdwood Grass (*Cenchrus setiger*) was introduced for fodder to Mundabullangana Station from a sample of seed sent from India (Van Vreeswyk 2004).

Table 1 gives the earliest known dates of recording of the presence of weeds in the Pilbara. Introductions have been documented at a steady rate since settlement began in 1863. As noted above, in the past there has been a significant lag phase between introduction and the collection of a herbarium specimen to indicate that a species has

naturalised. Most records before 1960 were made at major ports (most collectors also visited these) and pastoral station homesteads. Currently, most new records are found around towns and roadsides. The number of introductions of new weeds has not slowed over the reporting period (1861–2006), but the rate of detection has probably increased in the past decade. Herbarium collections are becoming a more accurate measure of the date of naturalisation.

Thus, some species have been introduced to the Pilbara several times, and for various reasons, since the original introductions to Australia. The main reasons in the past and present, however, remain for gardens, in contaminated soil (machinery, roads) and as pastoral plants.

Richness and biogeographical origins

After considering the revisions and changes noted above, a total of 103 weed taxa are currently established in the Pilbara (Table 1). The native flora of the Pilbara comprises 1521 taxa (Western Australian Herbarium 1998–, accessed 22 April 2010), hence of a total flora of 1624 taxa, 6.34% are naturalised, which indicates that the region is comparatively weed-free in terms of species of naturalised flora, although perhaps not in number of plants or extent of some species, such as Buffel Grass. Growth forms of naturalised species are mainly annual herbs (56) or perennial herbs (23), with a few trees (11), shrubs (12) and vines (2). There are 31 families represented in the weed flora, Poaceae (23), Fabaceae (16) and Asteraceae (11) having the highest representation.

Pilbara weeds originate mainly from areas with similar climates (Table 2), especially the Americas (34 species), Asia (27 species) and Africa (11 species). There is a smaller element of temperate weeds originating from Europe (10) and the Mediterranean to Western Asia (6), found mainly around towns of the southern and coastal Pilbara. Finally, there is a cosmopolitan element of nine species.

Taxa that are current or potential threats to the Pilbara

The Pilbara is a semi-arid region characterised by rugged terrain, external drainage by fresh permanent and seasonal rivers, coastal plains and complex patterns of alluvial plains created by the rivers. The large, fresh rivers and wetlands are a unique feature of the Pilbara compared with the desert regions of Western Australia, and any weed that affects these values adversely is significant. Examples of some of these are highlighted below.

The Pilbara remains relatively weed-free and quarantine measures at the national borders contribute to keeping out potential weeds from

Table 2 Geographic origin of Pilbara weeds.

Geographic area of origin	Number of taxa
AMERICA	
North America	8
South America	9
Tropical America	17
ASIA	
South West Asia	6
Tropical Asia to Australia	5
Africa to Asia	17
AFRICA	
Tropical Africa	8
Southern Africa	3
EUROPE	
Mediterranean	6
Europe	10
COSMOPOLITAN	
Tropical	4
Cosmopolitan	5

overseas. However, many weedy species that could pose a significant threat to biodiversity in the region are already present elsewhere in Australia and so cannot be addressed by national quarantine. Some of these occur in low numbers in the Pilbara. Martin *et al.* (2006) listed 622 non-native naturalised species from Australian rangelands, of which 160 species (26%) were considered to pose a threat to rangeland biodiversity. Subsequently, Grice and Martin (2006) listed 92 weeds as posing the greatest actual or potential threat to biodiversity in the Australian rangelands. They cited 20 as major threats to the Pilbara, of which 9 are here recorded as already present (Table 1) : *Calotropis procera*, *Cenchrus ciliaris*, *Jatropha gossypifolia*, *Leucaena leucocephala*, *Opuntia* spp., *Phyla* spp., *Prosopis* spp., *Salvinia molesta* and *Senna occidentalis*. Two others listed by Grice and Martin (2006), but not specifically identified as a threat to the Pilbara, are now known to be present: *Agave americana* and *Asphodelus fistulosus*.

A further eleven were listed as having the potential to invade the Pilbara Bioregion but have not yet been recorded, these being: *Acacia nilotica*, *Bryophyllum daigremontianum* × *delagoense*, *Carrichtera annua*, *Lepidium didymum*, *Cryptostegia grandiflora*, *Eichhornia crassipes*, *Lantana camara*, *Pennisetum polystachion*, *Sida acuta*, *Sida rhombifolia*

and *Zizyphus mauritiana*. In addition to those listed by Grice and Martin (2006), the following should be considered potential threats: *Brassica tournefortii*, *Cylindropuntia* spp., *Melinis repens*, *Zizyphus mauritiana* and *Xanthium strumarium*. These can be addressed through a combination of listing under the State Biosecurity Legislation, effective local quarantine to prevent spread to the region, and eradication of new populations before widespread establishment. Several are already Declared Plants under the *Agriculture and Related Resources Protection Act 1976*.

While it is not possible to predict accurately all Pilbara habitats that may be affected by many of these species, for some it is clear. For example, *Xanthium strumarium* (Noogoora Burr) is highly likely to invade watercourses and alluvial flood plains. Prevention of invasion or eradication of small populations of these weeds is a highly cost-beneficial option and should remain a focus of control efforts.

Grice and Martin (2006) noted that, in general, invasive plants reduce the diversity and abundance of native plants in invaded habitats. In this context, eleven species have been briefly discussed by McKenzie *et al.* (2009): *Acetosa vesicaria*, *Aerva javanica*, *Cenchrus ciliaris*, *C. setiger*, *Calotropis procera*, *Leucaena leucocephala*, *Phoenix dactylifera*, *Prosopis* spp., *Tamarix aphylla* and *Zizyphus mauritiana*. Table 1 lists weeds of the Pilbara, the purpose of introduction, the habitats they currently occupy and the earliest known record. Three groups warrant special mention—1, those that affect many habitats across the landscape, 2, those that affect specific habitats and 3, those on the islands.

1. Landscape-scale weeds (14 taxa)

These are weeds able to grow in many habitats, often becoming dominant. Generally they alter the habitats they invade by changing soil chemistry, fire regimes, competition or a combination of these. The following 10 taxa from this category are the major weeds of the Pilbara: *Acetosa vesicaria*, *Aerva javanica*, *Argemone ochroleuca*, *Cenchrus ciliaris*, *C. setiger*, *Chloris virgata*, *Indigofera oblongifolia*, *Malvastrum americanum*, *Prosopis pallida* and *Prosopis glandulosa* × *velutina*. The key source for this determination is Van Vreeswyk (2004). Of the 12,445 traverses that Van Vreeswyk *et al.* (2004) scored, 14% contained weeds. The most common species was *Cenchrus ciliaris*, recorded on 12% of transects and estimated to dominate the coastal plains and alluvial floodplains of the area, or some 3,434 km² of the Pilbara. *Aerva javanica*, *Malvastrum americanum*, *Acetosa vesicaria*, *Chloris virgata*, *Indigofera oblongifolia*, *Prosopis* spp. and *Argemone ochroleuca* were also recorded at several transects in a range of habitats.

From surveys for this paper, *Cenchrus setiger*, the two *Bidens* spp. and two *Stylosanthes* spp. were found to be increasingly widespread weeds of many habitats and are added to the list of landscape-scale weeds.

2. Weeds of specific habitats (15 taxa)

Fifteen of these species invade and severely affect localised habitats, especially the unique rivers and wetlands of the Pilbara which are invaded by the following taxa:

- *Phoenix dactylifera*, *Washingtonia filifera*, *Washingtonia robusta*, *Tamarix aphylla*, *Ricinus communis*, *Clitoria ternatea*, *Parkinsonia aculeata*, *Leucaena leucocephala* and *Leptochloa fusca* subsp. *uninervia* tolerate waterlogging/flooding and are major weeds of the river banks and courses;
- *Ceratopteris thalictroides*, *Salvinia molesta* and *Nymphaea macrosperma* are major weeds of water bodies;
- *Polypogon monspeliensis* is a salt-tolerant species that could be a major threat to the Fortescue Marsh;
- *Paspalum fasciculatum* is a potentially serious threat to the diverse freshwater claypans; and
- *Cynodon dactylon*, which is already regarded as the most serious weed of arid wetlands in central Australia (Duguid *et al.* 2002).

3. Weeds of the islands (6 taxa)

Although not included in the Pilbara Biodiversity Survey, the islands off the Pilbara coast contain a set of weeds that should be mentioned. These islands have unique biodiversity values, especially for their fauna, and are potentially at risk from the following weeds: *Opuntia stricta*, *Eragrostis curvula*, *Hyparrhenia hirta* and *Melinis repens*. Based on experience elsewhere, two others could become significant on the islands—*Jatropha gossypifolia* and *Asphodelus fistulosus*—which may invade alluvial, species-rich herblands.

Current control measures

Weed management in the Pilbara has progressed from documentation to active management aimed at reducing the establishment of new weeds, eliminating potential weeds, removing the threat to biodiversity of certain weeds, and planning to reduce the threat of landscape-scale weeds.

An active program is underway to reduce the establishment of new weeds, by replacing invasive exotics in gardens (Department of Environment and Conservation 2009). Most major mining developments now include weed management plans (e.g. Strategen 2006; Fortescue Metals Group 2009). These plans aim to prevent the introduction

of new weeds through mining operations, control existing weeds on mining leases, and reduce their impact and presence on rehabilitation areas. Both Cotton and Date Palms are under active control at Millstream (Kendrick 2005), as are the two major invasive aquatics, *Ceratopteris thalictroides* and *Nymphaea macrosperma*. Prickly Pear has been eradicated from the Dampier Archipelago. Attempts are under way to control the infestation of *Calotropis* on the De Grey River, with cost-effective methods devised by the Western Australian Department of Agriculture and Food (A. Reeves, pers. comm.).

Management plans are being prepared for several major weeds, including *Acetosa* (Anthony and Dixon 2006), *Parkinsonia* (Department of Water 2008) and *Prosopis* (Anderson *et al.* 2006; van Klinken *et al.* 2007; Land and Water Australia 2008b). Attempts are being made to limit the spread of Buffel Grass onto offshore islands (Dixon *et al.* 2002) and to prepare research and management programs on this weed (Friedel *et al.* 2007; Land and Water Australia 2008a).

A potential future risk is posed by pastoral diversification initiatives, especially when this involves growing crops for hay, pasture or bio-fuel. Many species grown for bio-fuel are known environmental weeds, some very serious and aggressive. Many proposed pasture species are weedy grasses that have the potential to become environmental weeds if not managed carefully, especially in riparian areas.

CONCLUSIONS

The weed flora of the Pilbara (103 taxa) is relatively small, being just over 6% of Pilbara's total flora. Compared with the 2004 listing of 84 weeds (Keighery and Longman 2004), this is an increase of 19 taxa (20%) in six years. While most likely an overestimate due to changes in designation of taxa (weed status and taxonomy), this increase is of concern. As most species were introduced intentionally as garden, amenity or fodder plants, there is a need for continuing quarantine to limit further introductions. There is also a need to keep track of the taxa that are currently present in small numbers but are considered to have the potential to expand.

Of the 103 weeds, 14 species affect the region at a landscape scale, altering fire patterns, modifying soil characteristics, or competing directly with native species. Another 21 significantly affect particular habitats, especially wetlands and islands. It is essential that management actions/plans be developed to focus on these weeds. Taxa that are currently present in small numbers but have the known or predicted potential to expand are another

priority for control measures. The actions by DEC to rank weeds for management actions are endorsed and should continue, as are current control actions.

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A understorey monoculture of Birdwood Grass (*Cenchrus setiger*), an environmental weed, on a bank of the De Grey River (G.J. Keighery).