Why are there so few weeds?

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Summary When cultivated plants become weeds they do not behave abnormally but only as one should expect them to. The key question is not 'Why do some plants become weeds?' but 'Why do most cultivated plants remain well behaved?' We may be asking these questions too soon, for we cannot yet measure the consequences of global mass movement of plants, most of which has taken place within the last 300 years – less than the lifespan of many individual tree species. Surveys showing that only about 10% of species naturalise are premature. Many more plants will escape in future, although we cannot predict which. The Australian Quarantine and Inspection Service Weed Risk Assessment works from unsound assumptions. I suggest reasons why most plants have not naturalised yet: 1) They cannot reproduce; 2) They lack a seed dispersal agent; 3) They are out competed by other plants; 4) They are suppressed by herbivores and pathogens; 5) Australia is unsuitable; 6) The opportunity to naturalise has not yet arisen (but will in future). My speculative overview suggests that existing cultivated plants are most likely to naturalise under three scenarios: after new stock is imported, after arrival of new pollinating bees, and when plants are finally grown in (or their seeds reach) localities that suit them best. Continuing importations of 'safe' plants pose a quarantine risk. Calls to introduce new crop-pollinating bees should be strenuously opposed.

Keywords Weeds, naturalisation, weed risk assessment, pollination, bees, bumblebees.

INTRODUCTION

Why do some cultivated plants escape and become weeds and not others? This, surely, is the most important question we can ask, given that our weed lists keep growing and that most new weeds (and old) are escapees from farms and gardens. Scientists often ask the question 'What makes a good weed?', but seldom ponder the corollary 'Why do most cultivated plants remain well behaved?'

The first question only is asked because weeds are perceived as anomalies. We define them as 'plants out of place'. They are miscreants, sometimes even 'thugs' (Randall 2002), doing what they should not. We humans have ordered the world to meet our needs, and weeds – like germs, toxic waste and terrorists – violate our organisation. Weed science is like the study of deviance, delinquence, or disease. And just as doctors can be criticised for treating illness rather than managing health, so can weed ecologists be challenged for treating weeds as anomalies.

The view of weeds as deviant plants goes with the belief that such plants have undesirable traits that distinguish them from other plants. Baker (1965) proposed that weeds share certain properties such as continuous seed production and short life cycles, implying a degree of predictability about such plants. This idea was addressed by the Scientific Committee on Problems of the Environment (SCOPE) program to study the ecology of biological invasions. This major international study ran for a decade and addressed three questions, the first of which was: 'What factors determine whether a species will become an invader or not?' (Williamson 1996). The conclusion drawn was that invasiveness cannot be predicted from an organism's properties. 'Baker characteristics have no predictive value for weediness', declared Williamson (1994), a leading biologist in the program. He concluded that 'Successful pests may have any life-form, can occur in any habitat, may have been introduced for all sorts of reasons, may come from anywhere and may have any form of reproduction. … It is not possible to get worthwhile predictions of pestiness from studying the characters of the plant (Williamson 1993a)'. Gilpin (1990) averred: 'we are never going to have a scheme to predict the success of invading species'.

This is a disturbing conclusion given that in 1997 the Australian Quarantine and Inspection Service introduced Weed Risk Assessment, a series of questions designed to assess the weed potential of new plants up for importation (Pheloung 2001, Walton 2001). A substantial proportion of the questions assume that weediness can be predicted from plant traits (for example, a climbing habit, stolons, thorns, toxicity, allelopathy). Weed Risk Assessment does have merit because it captures the one highly predictive value – weediness in one part of the world is often matched by weediness elsewhere (Panetta *et al.* 2001).

Invasiveness cannot otherwise be predicted with assurance because weeds are not anomalous plants. All cultivated plants are descended from wild organisms, from plants still growing in the wild, the products of many millions of years of competitive evolution. They exist to survive and reproduce. Australia embraces so many combinations of climate and soil that most plants in the world could surely find somewhere congenial here to grow, even if only in modest numbers. The question to ask is not 'Why are there so many weeds?'

but ‘Why are there so few?’ When cultivated plants escape into the wild they do not become ‘thugs’, they merely behave as one should expect them to.

People expect otherwise because our perceptions of plants have been shaped by the power we wield over objects. Garden plants are often presented to us as products selling in supermarkets alongside cereals and detergents. Under such circumstances, they appear to be more controllable than they really are. As Suzuki (1988) says: ‘We groom the planet in our image and see this as an indication that we are in control’. But as Lodge (1993) notes: ‘biological invasions are commonplace in nature, and should not, in general, be viewed as abnormal events’.

So why do so few plants escape our control? What holds the others back? If these plants are fending for themselves in the wilds of Madagascar, Mexico, Mauritius or Montana, why aren’t they making a go of it here? Living abroad confers excellent advantages. There is often respite from the specialised herbivores and diseases that blight a plant back home (Blossey and Nötzold 1995).

I expect that many of our seemingly benign plants — the ‘silent majority’ — will naturalise in future. I don’t claim they will become serious weeds (although some will), only that they will establish self-reproducing populations, perhaps infrequently in the short term and only in marginal habitats, for example in gullies near houses. I question those statistical surveys showing that, internationally, only about 10% of introduced species naturalise (Williamson 1993, 1994, 1996). Such findings are premature. Environmental processes operate on different time scales from human processes. People only began moving plants (and animals) around the world on a vast scale 200 or 300 years ago – less than the average lifespan of many a tree. This mass movement represents a major new global ecological phenomenon, now still in its early stages. Humans will not be in a position to catalogue all the consequences for thousands of years, if ever. The few studies which purport to show that certain categories of plants (e.g. plants with bird-dispersed fruit) become more invasive than others are premature. All they show, I fear, is that certain categories of plant invade more quickly.

Of plants that do not naturalise, or have not naturalised yet, I can think of six reasons why this might be so, each of which is considered further below: 1) They cannot reproduce; 2) They lack a seed dispersal agent; 3) They are outcompeted by other plants; 4) They are suppressed by herbivores and pathogens; 5) Australia is unsuitable; 6) The opportunity to naturalise has not yet arisen (but may in future).

It is evident that many cultivated plants, especially garden plants, do not manufacture seeds. This could be for several reasons: 1) They are sterile hybrids; 2) They have been bred to produce no seed (the banana, for example); 3) They cannot outcross because they are vegetatively propagated and genetically identical; 4) Both sexes are not present; 5) Genetic diversity is too low to overcome inbreeding depression; 6) They lack a suitable pollinator.

These barriers to reproductive success are formidable but in most cases not insurmountable. For example, seemingly sterile hybrids can, through chromosome doubling, become fertile (Reichard and Hamilton 1997). Sterile plants can propagate by vegetative means after garden dumping. Also, the missing sex can be introduced. Willows and pampas grass (*Cortaderia selloana* (Schultes & Schultes f.) Asch. & Graebn.) are both dioecious cultivated plants which became dramatically weedy after the missing gender was introduced, facilitating pollination and production of seed for the first time (Groves 1998, Rawling 1994). New introductions of the same species can also allow for outcrossing and overcome inbreeding depression. Panetta (*et al.* 1994) suggested that 10,000 accessions of about 5000 plant taxa are introduced to Australia each year, and that all but 500 of the taxa are species already in the country. This represents a vast augmentation of genetic material, even if the figure is an overestimate. New material of old plant species is let in on the assumption that the species has been found benign, when in fact the new introductions may invalidate that assumption.

Missing pollinators can also invade. Bumblebees (*Bombus* Latreille species) are the natural pollinators of hundreds of northern hemisphere plants, many of which are cultivated in Australia. These include foxgloves (*Digitalis purpurea* L.), rhododendrons (*Rhododendron* L. species), lupins (*Lupinus* L. species) and tomatoes (*Lycopersicon esculentum* Miller) (Goulson 2000). Bumblebees practise ‘buzz pollination’, triggering release of pollen when their vibrating bodies touch flowers, and flowers adapted for such pollination are often called ‘bumblebee flowers’. Free (1982) describes the bumblebee as ‘one of the most efficient pollinating insects in the world’. In 1992 the bumblebee species (*Bombus terrestris* L.) was deliberately or accidentally introduced into Tasmania, and today it is widespread there.

Goulson (2000) noted recently of the tree lupin (*Lupinus arboreus* Sims): ‘It is listed as one of the worst weeds of national parks in New Zealand, where bumblebees have been present for 100 years. The tree lupin was also introduced to Tasmania, but is not particularly common at present. Our recent research has shown a dramatic increase in seed set of this species in Tasmania in areas where bumblebees are now established. We could well be witnessing the awakening of a sleeper weed.'

Tasmanian daffodil farmers are also seeing higher seed set in their crops since bumblebees arrived. *B. terrestris* was imported into New Zealand more than a century ago, and has been recorded visiting the flowers of 400 species of introduced plant there (Donovan 1980). New Zealand is blighted by a number of weeds that prove less successful in Australia, for example the foxglove. Bumblebees in Australia may well add plants to our weed lists. They are likely to reach the mainland one day, either by crossing Bass Strait, or after smuggling by tomato farmers (Low 1999).

In December 1997 a yellow-faced bumblebee (*Bombus vosnesenskii* Radoszkowski) was collected at Buderim in southern Queensland. Someone had presumably smuggled it into the country, although no more individuals were found. This American species is bred to pollinate tomato crops in California.

During the 1980s and 1990s Eurasian leafcutting bees (*Megachile rotundata* Fabr.) were introduced into temperate Australia to improve pollination and seed set of lucerne (*Medicago sativa* L.) (Woodward 1994). They were also introduced to New Zealand, where, according to Donovan (1980): 'Wild leafcutting bees visit many flowers but those of pasture legumes and composites appear to be preferred. Managed bees mostly visit lucerne flowers or the flowers of other legumes or weeds in or near flowering lucerne fields'. These bees may allow daisies and lupins grown in Australian gardens to set seed and become weeds.

Other bees are buzzing at Australia's door. During the 1970s Asian honeybees (*Apis cerana* Fabr.) spread from Java into Irian Jaya, and in 1985 they reached New Guinea (Low 1999). In 1998 a hive was found in Darwin and quickly destroyed. Since then swarms have been found on ships in Brisbane (twice) and Melbourne. Also, in March 2000 a swarm of Asian giant honeybees (*Apis dorsata* Fabr.) was found at the Brisbane wharves. This species has been intercepted at other ports as well. Social bees make good invaders (Moller 1996) and the evidence suggests that Asian honeybees will establish in Australia sooner rather than later. Whether or not they improve pollination and seed set in cultivated plants remains unknown, but seems very possible, as they are highly regarded crop pollinators in Asia.

If, as seems likely, the Tasmanian bumblebees were smuggled in from New Zealand by a farmer, there is a small risk that other crop-pollinating bees (*B. hortorum* L., *B. ruderatus* Fabr., *Nomia melanderi* Cockerell (Donovan 1980)) could be smuggled in from New Zealand in future. We could also get a new bee from Timor. Giant calotrope (*Calotropis gigantea* (L.) W.T.Aiton) is a major weed in Timor (AQIS 2000) but a minor weed in Australia. Barbara Waterhouse (pers. comm.) suggests this is because big black bees visit the flowers in Timor but not here. If these bees invade Australia on ships returning from Timor they could generate new weeds.

Another possibility is that plants fail to naturalise because they lack any animal to disperse their seeds. I doubt this is a major explanation because native birds and flying foxes are known to feed upon and disperse the seeds of a wide range of exotic fruits, ranging from tiny berries up to mangoes. In one striking example an endangered bird, the cassowary (*Casuarius casuarius* L.), is dispersing the seeds of a weed of national significance, the pond apple (*Annona glabra* L.) (Low 2002); in one cassowary dropping, 850 pond apples seeds were found (Breaden 2001). Few of the plants grown in Australia rely upon specialised and unavailable dispersal agents, most fruit-bearing plants producing fruits that appeal to a range of birds. Exceptions may include oaks (*Quercus* L. species) which are dispersed overseas partly by squirrels, and the African sausage tree (*Kigela africana*) which produces enormous (up to 50 cm long) hard brown fruits attractive to baboons and bush pigs. But even these plants should be able to produce occasional adventive offspring close to parent trees. A lack of dispersal agents should not result in complete failure to naturalise, but rather in a failure to disperse effectively across the landscape.

Competition may also prevent many cultivated plants from establishing in the wild. Intact habitats, with native plant communities still in place, are usually relatively resistant to invasion. But the vegetation communities occurring close to cities, towns and farms, where most exotic plants are grown, are usually highly disturbed by clearing, nutrient enrichment, changed fire regimes and hydrology, track construction and quarrying. However, in such situations pre-existing weeds may well prevent some new species from establishing.

Some of our cultivated plants may be so modified by genetic selection that they are unfit for survival in any competitive environment. This could hold true for food plants, nearly all of which are genetically modified to a large degree. It is certainly true that major food plants, such as wheat and corn, rarely escape our control. But it is also true that food plants often become weeds, and more often than we think. The CSIRO's Handbook of Australian Weeds (Lazarides, Cowley and Hohnen 1997) lists more than a hundred foods and cultivated herbs as weeds. In an English study Williamson (1994) found that 'crop plants are far more likely to escape and survive than the typical imported plant'.

This holds true because genetic manipulation does not necessarily reduce a plant's ecological fitness. It can prove advantageous. Lantana (*Lantana camara* L.) one of Australia's very worst weeds (a Weed of National Significance), is 'an aggregate species derived through horticultural and natural hybridisation, selection and somatic mutation from a number of similar and probably closely related tropical species' (Day and Hannan-Jones 1999). Despite a huge effort, biological control has not worked well against this plant, largely because there is no *Lantana camara* in Latin America to collect biocontrol agents from, and no insects or diseases that evolved to attack this horticultural product. The prolific output of flowers, a character presumably selected for by horticulturists, ensures that lantana populations exchange plenty of pollen and keep adapting to local conditions.

It is surely significant that four of Australia's 20 worst weeds (Weeds of National Significance) are partly or entirely of hybrid origin – lantana, blackberry (*Rubus fruticosus* L. species), mesquite (*Prosopis* L. species), and willows (*Salix* L. species). It is thus unsafe to assume that cultivated plants, because of genetic changes, are uncompetitive in the wild.

Competition may well explain why many plants do not become weeds, but I do not believe it explains why most plants do not naturalise. In the disturbed environments around cities competition is often reduced and there are many opportunities for seeds to sprout in a variety of environments.

Another possibility is that many foreign plants cannot survive in the wild because of attack by local herbivores and pathogens. If this is a major factor there is remarkably little evidence for it. To be sure, some cultivated plants are readily attacked by wild animals (sugar cane for example) and native or introduced diseases (tobacco, avocado), but there is no evidence to suggest that most plants, including most garden plants, are so affected. Gardeners who live adjacent to bushland often succeed in growing a wide range of exotic plants in the presence of wallabies, possums, hares, rabbits, insects and pathogens. Furthermore, exotic plants have many opportunities to spread in the absence of some of these threats, for example into inner city vacant allotments. Herbivores and pathogens may explain why some plants fail as weeds, but they are unlikely to be a major explanation.

It must be true that the Australian environment is unsuitable for some plants. Although Australia is a continent, embracing a vast range of soils and climates, it is somewhat idiosyncratic. For example, rainfall in the outback is so irregular that very few arid zone plants are deciduous or succulent, unlike dry regions elsewhere (Low 1998, Low in press). But although this may well explain why so few succulents go feral, it does not explain why most of the garden plants grown in capital cities do not naturalise. Many gardeners do not water or otherwise tend their plants, yet these still flower and seed, suggesting that conditions are suitable for their survival and reproduction.

Another possibility is that many plants are capable of naturalising but the opportunity has not yet arisen. Either they have yet to be cultivated in a region with the right soils and climate, or if they have, they are locked inside cities where their propagules cannot reach the right substrate. Alternatively, they may require a rare cataclysmic event (fire, flood) to get going. At least three lines of evidence suggest that many plants fall into this category: 1) Some plants only naturalise after very long residence in Australia; 2) Studies show a correlation between introduction rates and naturalisation success; 3) Plants with succulent fruits make good weeds.

Groves (1998) found that ten new plants naturalise each year. Many of his recently naturalised plants have been grown in Australia for a very long time, for example the daffodil (*Narcissus pseudonarcissus* L.), sweet pea (*Lathyrus odoratus* L.), bay laurel (*Laurus nobilis* L.), Canary Island date palm (*Phoenix canariensis* hort. ex Chabaud), coffee (*Coffea arabica* L.), cashew (*Anacardium occidentale* L.) and poinciana (*Delonix regia* (Bojer) Raf.). Why did these plants take so long to naturalise? Was the opportunity slow to arise?

A number of studies around the world have shown that rates of invasion among exotic species are often correlated with scale of introductions (Mulvaney 2001). Mulvaney looked at naturalisation rates among woody plants grown in Canberra and other capitals and found a 'highly significant ($P < 0.001$) relationship between naturalised occurrence and the number of times a species had been planted…' Mulvaney drew the obvious conclusion from this, that 'many species currently grown in south-eastern Australian gardens, without yet becoming naturalised, have the potential to become serious invaders'. Mulvaney's findings could reflect the need for genetic diversity among invading plants, as noted earlier, as well as upon the opportunities provided for plants to spread their seeds.

Thirdly, it is noticeable that in eastern Australia most of the woody weeds invading forests are ornamentals that produce succulent fruits with seeds dispersed by birds (or bats). One might conclude from this that succulent-fruiting plants are more likely to become weeds than other plants. But a simpler conclusion is just that seeds from such plants more often find their way into forests. Other plants may be as well suited for life in the wild but get fewer opportunities to naturalise. Their careers as weeds will take off in future, when someone plants them in a garden on a forest edge, or dumps their seeds in a gully. Like Mulvaney, I suspect there are hundreds of plants growing in gardens that are capable of naturalising but which have yet to be afforded the opportunity. They will be helped along by the trend towards people living on acreage properties close to bushland.

Finally, it must be emphasised that our knowledge of naturalised plants is incomplete. How incomplete, we cannot say. Plants in the first stages of naturalisation, or with limited potential to naturalise, are likely to be rare and cryptic. In a major survey of the Mackay coast Batianoff and Franks (1998) found that about 78% of exotic species were 'infrequent or locally rare'. In Victoria numerous exotic plants have found their way onto weed lists only because of the observations of one assiduous observer, consultant Geoff Carr. Indeed, of the 290 new weed species recorded in Australia between 1971 and 1995, more than 60 were documented by Carr (Groves 1998). If Australia had a thousand Geoff Carrs combing the continent our national weed list would be considerably longer.

North Queensland is one region that probably harbours many cryptic weeds. I recently received a letter from a resident there complaining about a trumpet tree (*Cecropia* species) he planted producing feral young. A Queensland government weed officer, Vic Little, visited the property and confirmed that the plant was behaving like a serious invader. This genus is not recorded as naturalised in Australia (Randall 2001), nor is it listed as a potential environmental weed by Csurhes and Edwards (1998), although obviously it is. Many residents in the north are growing unusual plants (rare palms, bromeliads, ferns, alternative food crops) close to Wet Tropics rainforests and wetlands. Little told me he visited the property of one plant importer about ten years ago and helped document several plant species naturalising in Australia (on this property) for the first time. No plant officer has ever returned to that property.

CONCLUSIONS

Groves (1999) has warned us recently about 'sleeper weeds' – plants that have naturalised without yet become widespread and significant weeds. My concern here is with weeds one step removed – that is, with the many thousands of plants that are not (yet) doing what biology dictates they should, which is to naturalise. Groves berates weed scientists for neglecting sleepers, and I believe non-naturalised plants deserve more scrutiny too. Mulvaney (2001) issued the same warning. There can be no doubt that many of today's 'benign' cultivated plants will go feral in future, but we don't know which, or when. My speculative overview suggests that new plants are most likely to naturalise under three scenarios: after new plant stock is imported, after arrival of new pollinators, and when plants are finally grown in (or their seeds reach) the settings that best suit them.

The first scenario has serious quarantine implications. As Mulvaney (2001) noted: 'To date, applications of weed risk assessment have largely been directed at new introductions into a country or other government area. The result obtained from the present study is an ominous warning that weed risk assessments should also be focused on species already present'. Unfortunately, this warning runs up against Australia's legal obligations. For as Walton (2001) notes: 'Only plants that do not occur in Australia and which are assessed to be quarantine pests, can be prohibited importation under international agreements…' Exceptions can be made for new varieties and lines of existing plants, since their propensity to weediness may differ from that of earlier lines.

The second scenario underscores the need for the federal government to resist pleas to introduce new bees as crop pollinators. These short-sighted pleas are coming both from the CSIRO (Cunningham 2001) and from tomato farmers in New South Wales who want bumblebees. Varroa mites, which kill honeybees, are likely to invade Australia soon on invading Asian honeybees or on smuggled queen honeybees. The mites reached New Zealand with smuggled honeybees in 2000, leading Cunningham (2001) to conclude: 'Research in the US, where honeybees have dramatically declined because of mites, has identified the potential of a number of bee species as commercially managed crop pollinators. A similar research effort should be developed in Australia.' This proposal is dangerous. Cunningham admits that new bees could harm native pollinators and become pests or disease vectors, but fails to acknowledge that new bees will bring new weeds out of the closet.

The third scenario highlights the need for constant vigilance towards the plants we grow. The past does not predict the future, and weeds are not unusual plants. When crops and garden plants naturalise they only do what biology dictates they should do. We should expect to see more and more of them on our weed lists in future.

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