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REVIEW

A case for assessing *Allocasuarina* and *Casuarina* spp. for use in agroecosystem improvement in semi-arid areas with a focus on Central Anatolia, Turkey

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Abstract Agroecosystems in water-limited contexts—Mediterranean, semi-arid and arid climatic zones—are too frequently degraded systems that will not provide the needed ecosystem services to ensure a future of sustainable agricultural production. The processes that have created this situation continue and are being accelerated by anthropogenic climate change. Increasing arboreal vegetation in these areas through agroforestry is an important strategy to conserve and improve their agroecosystems. Actinorhizal trees and shrubs in the Casurinaceae have a unique set of adaptations for heat and water stress, and/or infertile to hostile soils. Central Anatolia, Turkey is particularly at risk of increasing aridity and further degradation. Therefore, species of *Allocasuarina* and *Casuarina* have been evaluated for their potential use in agroecosystem improvement in semi-arid areas with a focus on Central Anatolia. Based on a semiquantitative environmental tolerance index and reported plant stature, eight species were identified as being of high (*A. verticillata* and *C. pauper*) to moderate (*A. acutivalvis*, *A. decaisneana*, *A. dielsiana*, *A. huegeliana*, *C. cristata* and *C. obesa*) priority for assessment, with none of these species having been adequately evaluated for agroforestry deployment in semi-arid agroecosystems in any context.

Keywords actinorrhizal trees, agroforestry, climate change, ecosystem restoration

1 Introduction

The importance of agroecosystem services for the future of sustainable agricultural production is increasingly recognized. With the development of transhumant and sedentary agriculture, the pre-agrarian ecosystems were changed irreversibly by land cleaning, cultivation and intensified grazing into what are now known as agroecosystems. Although simpler systems with a high degree of anthropogenic alteration, agroecosystems can be sustainable and productive. However, with the intensification of agricultural production during the 1900s, including increased use of mechanization, fertilizers and agrochemicals, improvement and consequent narrowing of crop genotypes, loss of remnant native vegetation, larger farms and declining rural populations, many agroecosystems are now considered degraded. There is clear need for improvement of these systems to ensure future sustainability, especially if increased production levels are to be realized or even current levels maintained.

Biologically diverse agroecosystems can provide many beneficial ecological services that can reduce the need for off-farm inputs to improve the economic efficiency of agriculture production and reduce negative environmental impacts, locally, regionally and globally. For example, conservation agriculture with no (or minimal) cultivation can reduce fuel inputs, compaction, erosion, run-off and evaporation, but most importantly it can increase soil organic matter and thereby diversity of soil organism benefiting nutrient cycling and root health. Likewise, increasing agroecosystem biodiversity through crop and cultivar rotations can be beneficial for weed, pest and pathogen control, and biological nitrogen-fixation. Increasing the biodiversity of perennials, such as trees, can provide habit and refuge for organisms beneficial to integrated pest management, as well as for native flora and fauna, as well as moderate microclimate for reduced wind damage and evaporation rates.

Restoration and/or improvement of agroecosystems, although clearly a worthy, if not essential, undertaking, is not something that can be achieved simply or quickly. Indeed, the degradation of agricultural land and environments is a multi-causal problem with constantly changing

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dynamics and many stakeholders. It has been described as a *wicked* (highly complex) problem; such problems have no single solution, and many barriers for finding and implementing solutions, with some attempted solutions actually exacerbating the problem[1]. These problems are considered to be unsolvable, and not even understandable, by a single organization, with consensus between organizations on causes and solutions unlikely. So a range of possible partial solutions need to devised and tested by different contributors both collaboratively and independently.

Restoration of semi-arid environments in urban, agricultural, pastoral and non-production (including protected areas) contexts is particularly problematic. Low rainfall means the productivity of the systems is low, so biological processes take longer to achieve. Semi-arid areas generally have naturally less fertile soil, which is alkaline to depth with consequences for nutrient availability[2], a higher frequency of drought[3] and other constraints to restoration. Also, the on-going processes of degradation, erosion, nutrient and organic matter depletion[4], and declining biodiversity, mean that restoration efforts have to built on shifting sands (metaphorically and sometimes even literally). In addition, agriculture in semi-arid areas is generally less productive, so returns on investment in ecosystem restoration will be lower and risks higher than in higher rainfall areas. However, a major proportion of the world's food production is in low-rainfall areas[3], so despite the economics the need is imperative.

Turkey has large areas of semi-arid agriculture, especially in Central Anatolia which is classified as an anthropogenic steppe with a semi-arid continental climate[5]. Sedentary farming and grazing in the region has been practiced for an extended period dating back to the Neolithic Revolution with one of the earliest proto-cities, Çatalhöyük (Çatalhöyük Research Project website), having been unearthed on the Konya Plain. The impact has been major changes in vegetation and the almost complete deforestation of the region[6,7]. So the current agroecosystems will bear little resemblance to the former pre-agrarian ecosystems. Upslope soils will have been truncated and improvised, and downslope accumulating areas completely changed. The loss of the ancient forests is also likely to have impacted on aspects of climate[8] including temperatures (particularly soil temperatures) and rainfall (which has been documented for contemporary Mediterranean and tropical climate deforestation)[9,10]. Consequently, reversing the degradation of Central Anatolian ecosystems and the establishment of a productive and sustainable agroecosystem is a complex matter.

Reafforestation has been actively pursued in Turkey for some decades, however, Lund[11] suggested that up-to-date statistics are not readily available and that there are some definitional uncertainties. Nevertheless, it is identified as a key element of the national climate change plan[12]. However, an impetus for economic agroforestry and using trees in agroecosystem restoration has not been given any particular priority. Various kinds of agroforestry are part of the traditional farming systems, but these have only minimal recognition in academic and institutional programs[13]. Tree planting in Turkey has been mostly for silviculture purposes and amenity (protection) plantings (e.g., associated with major road construction and as buffer planting around urban areas), rather than with specific agroecosystem goals. Consequently, tree plantings have almost always been direct planting of the desired species for the long-term. This might mean that the process has been less than optimal, as species selection was based on the benefits offered by the mature planting rather than the benefits offered by a successional process.

Lingley and Jazdzewski[14] bemoaned the fact that in the case of mining site rehabilitation, that institutions, even those fully aware of ecological principles, demanded climax flora to be established immediately. The same erroneous expectations have applied to reafforestation and agroecosystem restoration. Krawczyk[15] addressing this issue, states that restoration of sustainable forest ecosystems requires an ecological succession using early-colonizing (pioneer) species. The analysis of Prach and Hobbs[16] shows that for high-stress contexts (such as semi-arid regions of Turkey) contrived ecological succession is more likely to be successful. Though given the extended timelines for achieving agroecosystems objectives in semi-arid contexts, it is not surprising that succession approaches are not common. The FAO guidelines for restoration in drylands talks about assisted natural regeneration using methods to accelerate natural succession[17], mentions the planting of pioneer grasses, but does not mention planting woody nurse species or pioneers as an initial step in an assisted succession.

The planting of woody pioneers for semi-arid area restoration, although a long-term strategy, is an approach that should be the subject of more consideration and research. For the Central Anatolian context, the concern is that without action, current trends, accelerated by global warming, could lead to widespread desertification[18,19]. Given that Turkey does not currently have deserts (Table 1), the native woody pioneers are less likely to be suitable for succession restoration than species from more arid countries. One source of suitable species might be the semi-arid areas of Australia, a continent that is mostly semi-arid to arid (Table 1; Fig. 1) with many plant taxa having adaptations enabling survival and growth in infertile soils[21]. Also, the continent's arid areas are generally well vegetated with species able to tolerate fluctuations in water availability and severe water stress[21].

The aim of this paper is to consider the merits of wider evaluation of species of *Allocasuarina* and *Casuarina* for semi-arid ecosystem improvement. These genera have species with adaption for arid climates that overlap those currently in Turkey (Fig. 1(b)), but also for more arid

Table 1 Comparison of arid and semi-arid agroecological zones between Australia and Turkey

Agroecologial zone	Australia		Turkey	
	Area/ha	Proportion/%	Area/ha	Proportion/%
Desert/arid	319012	40.4	14	0
Dry, good soils	4700	0.6	2310	2.9
Dry, moderate soils	122784	15.6	17589	21.9
Dry, poor soils	178600	22.6	12685	15.8
Total arid/semi-arid	625096	79.2	32598	40.6

Note: Source from International Institute for Applied Systems Analysis (IIASA) website.

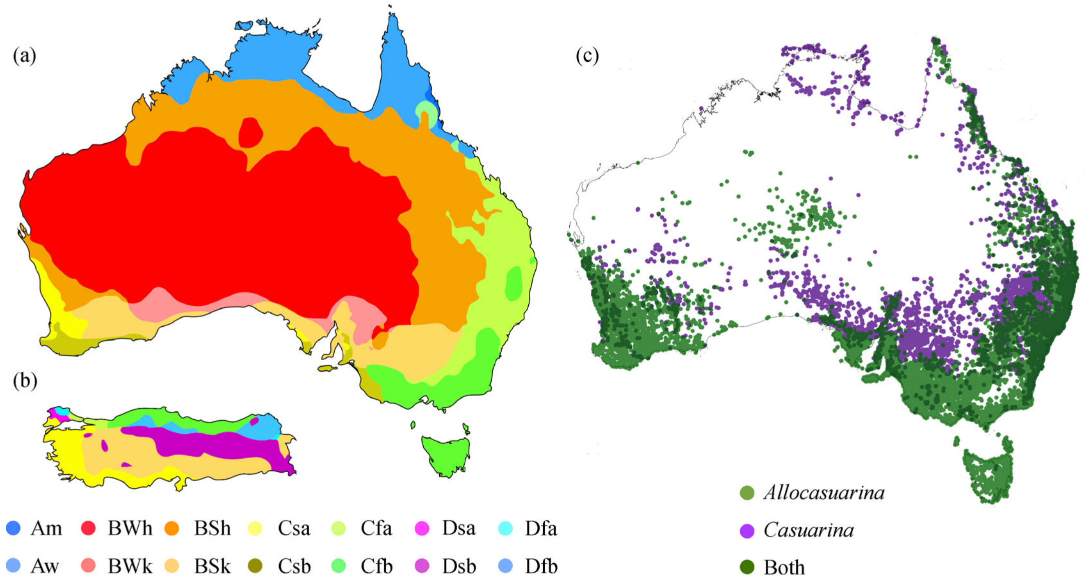

Fig. 1 Köppen climate classification for Australia (a) and Turkey (b), and the distribution of records of *Alllocasuarina* and *Casuarina* spp. in Australia (c). Köppen climate codes: Am, tropical monsoon; Aw, tropical wet and dry; BWh, hot desert; BWk, cold desert; BSh, hot semi-arid; BSk, cold semi-arid; Csa, hot-summer Mediterranean; Csb, warm-summer Mediterranean; Cfa, humid subtropical; Cfb, temperate oceanic; Dsa, Mediterranean-influenced hot-summer humid continental; Dsb, Mediterranean-influenced warm-summer humid continental; Dfa, hot-summer humid continental; Dfb, warm-summer humid continental (source from Peel et al.[20]). Plant distribution map source from Atlas of Living Australia (ALA) website (accessed on July 18, 2018).

climates that might develop in Turkey with climate change. Therefore, the focus of this paper is the agroecosystems of semi-arid cropping areas in the cold semi-arid climate (BSk, Fig. 1(b)) of Central Anatolia, Turkey. It is not intended to provide a comprehensive summary of the botany and ecology of the target species or their microbial associates here, and readers who need more detail on these are directed to the Flora of Australia (pp. 100–174)[22] for systematics, a monograph on the history of Australian flora (pp. 407–409)[23] for paleontology, and the proceedings of the five international workshops[24–28] for use in silviculture and agroforestry, and a recent review of the biogeography and ecology of the genus *Casuarina*[29]. Likewise, for detailed aspects of agroforestry, readers should refer to an excellent monograph on the subject, *Agroforestry for Natural Resource Management*[30].

2 Ecological status of semi-arid cropping areas

Semi-arid ecosystems have been especially impacted by a long history of clearing, cropping and intensified grazing. It is likely that the impact will have been greatest in areas were dryland agriculture has been practiced for millennia. However, even in Australia, where large scale land clearing is relatively recent, the magnitude of the impact in semi-arid areas has been enormous[31–34]. There has been considerable loss of local biodiversity, high rates of species extinction and loss of habitat for native flora and fauna. In addition, large numbers of invasive plant species have been introduced, with many agroecosystems dominated by exotic species. Also, introduced herbivores (domestic livestock and feral rabbits) and predators (foxes and feral cats) have impacted on native plants and animals. There has also been considerable soil loss through wind and water erosion, and soil degradation through dryland salinity and loss of organic matter[35,36]. Given the nature and scale of impact in Australia has been so great in such a relatively short time, the impacts in areas such as Central Anatolia must have been equally or even more severe.

Central Anatolia has a long history of agricultural impact, that includes periods of abundance and famine, aridity, erosion, deforestation and reforestation, and abandonment and recolonization[37,38]. Periods of warmer and drier climate have had devastating effects and are considered to have been driven by global processes[37]. However, it is not inconceivable that localized effects of deforestation[10] also contributed to Anatolian agroecosystems being vulnerable to climate change. With Anatolia now seen as being at particular risk from anthropogenic climate change and other human impacts[18,39], it should be a priority region for agroecosystem improvement. There is not only an economic impetus for this, but it would also help conserve Central Anatolian flora[40] and fauna. Although the Central Anatolian climate is considered the least favorable for tree growth in Turkey, the loss of arboreal vegetation appears to have been mostly anthropogenic[41], so aspirations to reverse of this situation should not be seen as unachievable.

Indeed, the *Republic of Turkey Climate Change Strategy 2010 2023*[12] recognizes the importance of increasing tree populations in the semi-arid areas of the country. For its green gas emission control, it sets a medium-term goal to identify and plant drought tolerant trees, especially in the arid and semi-arid areas; vegetation activities will be carried out in the areas in which afforestation is difficult and costly. Additionally, for adapting to climate change, it sets a short-term goal to develop and expand activities to combat desertification and erosion, which undoubtedly would involve increasing the resilience of marginal agroecosystems by planting drought tolerant trees. These and other short-, medium- and long-term goals, relate to agroecosystems, however, the plan does not explicitly identify agroforestry as a strategy. Whereas, the FAO in its *Save and Grow*[42] proposal for *a new paradigm of intensive crop production* explicitly identifies agroforestry as an important strategy for rebuilding robust and productive agroecosystems, especially in semi-arid environments. Both the Republic of Turkey and the FAO see semi-arid agroecosystems as degraded or at high risk of degradation, and urgently in need of active improvement.

3 Potential for trees in agroecosystem improvement

By definition the key plants and animals in agroecosystems are economically-beneficial domesticated species, including trees grown for fruit, nuts, forage, fuel and timber. However, the majority of the biodiversity in agroecosystems will be wild species, both indigenous and exotic, including microflora, annual and perennial plants, resident and non-migratory invertebrate and vertebrate animals. Many exotic species will be economically-damaging species (plant and animal pathogens and parasites, herbivorous invertebrates and vertebrates, invasive weeds and predatory animals), but also some indigenous species[43] will have negative economic impacts in agricultural systems, particularly in areas where agriculture developed in antiquity. Although trees usually only represent a small proportion of the overall biodiversity in agroecosystems, their ecological and economic benefits can be substantial, and increasingly well recognized[30].

Trees are woody perennials that generally grow to over 5 m tall and, therefore, have impact in vertical space unlike most other plants in agroecosystems. Also, with height also comes depth, so trees have roots systems that explore deeper into the soil than most annuals or smaller perennials. Therefore, trees provide a uniquely large range of ecosystem services. Their height can reduce surface wind speeds and wind erosion, provide shade for domestic animals as well as habitat and refuge for native animals (including invertebrates), favorably moderate the local microclimate, and even increase atmospheric water capture and precipitation rates[44]. Being large perennials, they can be productive contributors to carbon sequestration, and increase soil and surface organic matter, and a source of economically useful materials other than food (timber, fuel, fodder and more). The deeper roots extract and cycle nutrients and utilize water resources not available to other plants. The benefits of trees range from local climate, biodiversity and economics through to regional and global climate. Of course, trees in agroecosystems can also compete with crops, increase fire risk, reduce ground and surface water storage, and even be a source of allergens impacting on human health. However, on balance, trees offer great potential for agroecosystem improvement.

Realizing the potential benefits of increased tree populations in agroecosystem is a slow and uncertain process[45], but nevertheless is seen as crucial for the future of food production[42] and the maintenance of biodiversity, and other conservation objectives, in an increasingly anthropogenically impacted world. Unlike the main agricultural crops, which consist of a relatively small range of species, there is estimated to be over 60000 tree species with about 15% considered to be in danger of extinction[46]. So clearly, using trees for agroecosystem improvement can also directly and indirectly (by slowing or preventing the on-going expansion of agricultural land) help in the conservation of tree species. Thus, the selection of tree species for assessment for agroforestry needs to consider their utility and effectiveness in provision of ecosystem service, but also the wider consideration of preserving biodiversity.

4 Species selection for agroecosystem improvement

Imperatives of agroecosystem services and biodiversity conservation (or restoration) will impact on species selection for agroforestry. To maximize biodiversity benefits, it is recommended that locally indigenous species are planted with an understory of local shrubs, because this is likely to be best for conservation of local wildlife[47]. This recommendation is also built on the assumptions that locally indigenous species (1) will be adapted to the local environment, (2) can provide the desired agroecosystem services, and (3) are practically and economically suitable for propagation and established. Salt and Freudenberger[47] acknowledged that in some circumstances local species might not be suitable in contexts where conditions have been altered, and they cite dryland salinity as such a situation.

Thousands of years of anthropogenic impact have significantly altered conditions in Central Anatolia, so the concept of exclusively or preferentially using locally indigenous species is unlikely to apply to the extent that it does in countries like Australia. In addition to altered conditions, there are also other reasons that local species might not be the optimal choice. For example, in the Australian context, they might increase fire risk and in the Turkish context, some of the local species are already in serious decline from biotic and abiotic stress, so attempts to reintroduce local species to agricultural areas might not always be successful. For examples, indigenous *Quercus* spp.[48,49], *Abies cilicica*[50], and *Populus nigra*[51] are all in decline in Turkey due to pests and/or diseases, increasing aridity and genetic introgression, therefore selection of these species for agroforestry may not achieve biodiversity and ecosystem service goals.

Some indigenous species are already being used or considered for ecological rather than silvicultural purposes in Central Anatolia, and the challenge of species selection is well recognized[52]. Large areas of trees have been planted for revegetation purposes since the 1960s, but often with limited success that is considered to be due to inadequate research[52], particularly in species selection. In the study of Yildiz et al.[52], *Elaeagnus angustifolia* was considered to offer significant potential for arid land reafforestation. Notably, this species is considered a seriously invasive species in Canada and the USA, and well adapted to infertile soil because its roots are nodulated by the nitrogen-fixing actinomycete, *Frankia*[53]. Mostly, *Pinus nigra*, has been planted, but its survival and growth can be far from optimal, especially in sites with greater water stress[52], so a range of other indigenous species are under consideration[54].

Local growing-conditions have changed in deforested areas, but importantly they are also subject to on-going climate change. In Central Anatolia increased aridity is predicted, therefore, species selection for reafforestation also needs to consider future conditions. This is well illustrated by the loss of anthropogenically-distributed trees in sub-Saharan Africa due to climate change[55]. Given that Turkey does not have highly arid areas, some exotic species might need to be considered. If this concept is accepted, pioneer species from the semi-arid and arid areas of Australia could be considered. There are nearly 3200 tree species in the Australian biome[46,56] with many from the continent's large areas of arid land (Fig. 1). In contrast, Turkey has only about 185 tree species[56], so the Australian biome undoubtedly offers a potential resource for tree species for agroforestry in Turkey.

Exotic species are axiomatically considered unacceptable in biodiversity restoration programs in natural environments, but this should not be the position taken for agroecosystem improvement. In most instances agriculture species are exotic, but nevertheless valuable. Likewise, trees species for agroforestry should not be limited to indigenous species[57]. Exotic species may be of direct value, but can also be used as pioneers in a technical succession to a predominately indigenous biome, especially in high stress contexts, such as Central Anatolia[16]. In fact, the vast majority of global ecosystems are anthropogenically modified[58] and this process is predicted to continue with historical ecosystems going through transition to novel ecosystems. Even valued anthropogenic landscapes are subject to this change and can become the focus of conservation efforts (e.g., Thomas and Palmer[59]). So there exists a tension between preserving the existing and ensuring that the inevitably-novel agroecosystems of the future will provide the needed services.

Boydak and Çalışkan[54] prudently state, "... for the exotic species not tested yet, decision[s], concerning whether they should be planted on the afforestation sites in semi-arid and arid areas, should be made after conduction [sic.] of essential adaptation trials...". So in summary, it is widely agreed that Central Anatolia needs more trees, and here it is proposed that tree species from the semi-arid to arid regions of Australia be assessed for this purpose. One group of Australian trees worthy of particular consideration in this regard is the sheoaks (F. Casuarinaceae), many of which are trees (and large shrubs) that grow in high stress environments.

5 Agroecosystem potential of *Allocasuarina* and *Casuarina*

In Australia, the Casuarinaceae consists of species in three genera, *Allocasuarina*, *Casuarina* and *Gymnostoma*, with 61, 6 and 1 species, respectively. *Allocasuarina* and *Casuarina* are found throughout Australia with distributions extending into Mediterranean, semi-arid and arid climate zones (Fig. 1), and all have foliar and root adaptions that enable them to grow in relatively harsh environments and infertile soils. In the former two genera, there are 29 species of trees and shrubs (>3 m) that are considered here (Table 2; Fig. 2) for their potential use for agroecosystem improvement in semi-arid areas outside Australia, specifically in Central Turkey.

Australian sheoaks have already been widely adopted for forestry, agroforestry and other purposes in east, south and south-east Asia, mostly in subhumid to humid contexts with lesser use in semi-arid to arid contexts[28], and also in Africa including some relatively low rainfall contexts[60]. Most research and deployment has been with three Australian species (*C. cunninghamiana*, *C. equisetifolia* and *C. glauca*) and one Indonesian species (*C. junghuhniana*), being the larger more productive species. These species are not found naturally in lower rainfall areas (Table 2; *C. cunninghamiana* does extend into some hot, semi-arid areas in Queensland, but only along inland water courses), although *C. equisetifolia* and *C. glauca* are considered to exhibit useful drought tolerance[61,62]. Some *Allocasurina* spp. have been used in Africa, viz. *A. littoralis*, *A. torulosa*, *A. verticillata*[60], but only *A. verticillata* occurs naturally in low-rainfall areas (Table 2). A wider range of *Allocasurina* species was introduced to China[63], but there is no information on their adoption.

In the above contexts sheoaks have commonly been adopted for silvicultural purposes, however, they also can provide a wide range of other economic and ecological benefits. In introducing guidelines for restoration of arboreal vegetation in dryland areas, the FAO classifies these diverse benefits as provisioning, regulating, habitat (supporting) and cultural services[17] to indicate the breath of economic, environmental and ecological services, and even benefits for a society's sense of well-being. Of course, the value of these services is greatest where they in shortest supply—degraded dryland environments. Among the many plant species that could contribute to restoration of semi-arid areas, *Allocasuarina* and *Casuarina* hold some unique potential, but this potential needs to be balanced against any potential risks of introducing exotic species to new environments[29,64].

5.1 Adaptive advantages

Allocasuarina and *Casuarina* species have a range of biological and ecological features potentially making them suitable for agroecosystem improvement in harsh environments. These include their unique set of above- and below-ground adaptations, and their ability to be primary colonizers of disturbed and infertile (in the broadest sense) sites, and to persist as dominant species in sites unsuited to other arboreal species.

Allocasuarina and *Casuarina* have narrow elongated photosynthetic internodes (branchlets) with leaves reduced to small scales at the nodes, with stomata positioned deep within longitudinal stem grooves and a waxy surface[65]. In species more highly adapted to aridity, these grooves contain a large number of epidermal trichomes to further control evapotranspiration[65]. So sheoaks do not having foliage consisting of photosynthetic leaves, but rather a crown of dropping photosynthetic branchlets1), which is a key feature providing adaption for heat and water stress. The narrow, pendulous branchlets of low horizontal surface avoids overheating from incident sunlight and radiant heat. The position of stomates in stem grooves, filled with epidermal hairs in some species, facilitates reduced evapotranspiration under water stress. The nature of the crown (including the waxy surface) can also limit damage in contexts of high wind speeds and salt laden ocean spray. As the branchlets function as leaves, they are not all retained, with most being shed by cladoptosis, and as the branchlets are more fibrous than most leaves this leads to a thick, slowly degrading mulch layer[66]. This mulch can be beneficial a water limited environment by reducing competition from other plants, particularly annuals, and by improving water infiltration and reducing run-off below the canopy, and reducing pH of the mostly alkaline[2] arid-zone soils.

Although the above ground features of sheoak are ecologically significant, and make these taxa distinctly recognizable, it is their below ground adaptations that particularly justify their assessment for agroecosystem restoration in the more arid environments. They are deep-rooted perennials well adapted for seasonal and/or environmental aridity2). Their nodulation by nitrogen-fixing *Frankia*[68], development of cluster roots (functionally similar to proteoid roots in the Proteaceae)[69] and colonization by symbiotic mycorrhizal fungi, both vesicular-arbuscular mycorrhiza and ectomycorrhiza[70] for the infertile, and sometimes hostile, soils of semi-arid areas (as are common in Central Anatolia)[71] are additional advantages.

As a consequence of these morphological and microbial features, sheoaks function in their native ecosystems in ways that also indicate their potential for use in agroecosystems. *Casuarina* spp. in the more temperate environments are pioneer species of disturbed and infertile sites[69] and three species have become problematic

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1) The appearance of the crown is superficially similar to some *Pinus* spp., which has led to the use of inaccurate and misleading common English names, such as Australian pine.

2) There is limited quantitative data on root system depth and structure of *Allocasuarina* and *Casuarina* species, but Pate et al.[67] provides information for *Allocasuarina humilis* which is likely to be indicative of the group more widely.

Table 2 *Allocasuarina* and *Casuarina* trees and shrubs (> 3 m) from Australia with indication of their relative range and Köppen climate zones in which they occur naturally

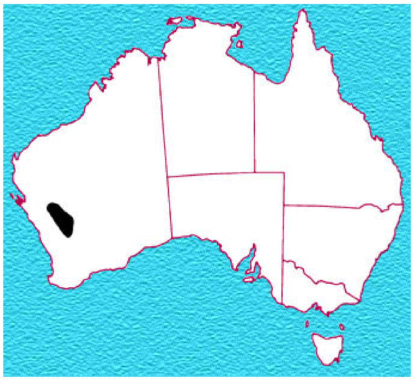
Species	Occurrence[1]	Stature and growing conditions[2]	Range[3]	Köppen climate zones[4]					
				BWh	BWk	BSh	BSk	Csa	Csb
A. acutivalvis	WA	Shrub to small tree, 2.5–8 m high. Lateritic and sandy soils. In tall heath, open woodland, rocky hillsides	XXX	●	●	●	●		
A. decaisneana	NT, SA, WA	Tree, 10–16 (–20) m high, the cones are the largest of all the species. Red sand. In swales between sand dunes	XXX	●		●			
A. decussata	WA	Tree (rarely shrub), to 15 m high. Loamy forest soils	XX				●	●	●
A. dielsiana	WA	Tree, 4–9 m high, male spikes globular. Red stony soils over granite, hilly country	XXX	●		●		●	
A. diminuta	NSW	Shrub or small tree, 1–5 m high. Sandstone ridges and upper hillsides	XXX			●			
A. duncanii	Tas	Small tree, to 8 m high. Shallow soils over dolerite, some on sandstone and almost monotypic scrubs on dolerite pavements	X						
A. fraseriana	WA	Erect tree, 5–15 m high, bark fibrous, reddish-brown. Lateritic soils, white, gray or yellow sands and sand dunes	XXX					●	●
A. grampiana	Vic	Shrub, 1–4 m high. Sandstone outcrops	XX						
A. gymnanthera	NSW	Shrub or small tree, 2–5 m high. Sandy soils on sandstone ridges	XX						
A. helmsii	SA, WA	Shrub, 1–5 m high. Wide range of soils	XXX	●	●	●	●		
A. huegeliana	WA	Tree, 4–10 m high. Associated with granite	XXX	●	●	●	●	●	●
A. inophloia	NSW, Qld	Small tree, 3–10 m high. Ironstone or sandstone ridges	XXX			●			
A. lehmanniana	WA	Shrub 1.5–4 m high. Coastal sandy-loam and sandy soils	XXX				●	●	●
A. littoralis	NSW, Qld, Tas, Vic	Tree, 5–15 m high. Sandy or otherwise poor soils	XXXX						
A. luehmannii	WA	Shrub, 0.5–4 m high. Sandy soils, clay, laterite, gravel. Coastal areas, winter-wet depressions	XXXX			●	●		

(*Continued*)

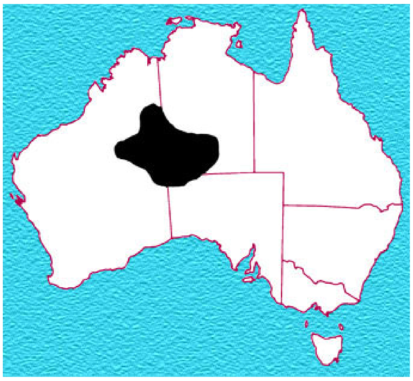
Species	Occurrence[1]	Stature and growing conditions[2]	Range[3]	Köppen climate zones[4]					
				BWh	BWk	BSh	BSk	Csa	Csb
A. monilifera	Tas	Medium shrub, to 5 m high. Wide range of soils from sand to clay, coastal heaths to subalpine scrub	XX						
A. portuensis	NSW	Shrub, 3–5 m high. Sandstone slope	XX						
A. rigida	NSW, Qld	Shrub, 0.5–4 m high. Poor sandy soils on acid granite, rhyolite or trachyte, in exposed situations	XX						
A. spinosissima	WA	Shrub 2–4 m high. Sandplains	XX	●	●	●	●		
A. striata	SA	Shrub or small tree 1–4 m high. Lateritic or sandy soils	XX						●
A. tessellata	WA	Shrub or tree, 3–5 m high. Loam, sand, and greenstone and dolerite areas	X	●		●			
A. torulosa	NSW, Qld	Slender tree, to 15–20 (–30) m high. Forest soils with higher-nutrient soils and in moister situations	XXXX						
A. verticillata	NSW, SA, Tas, Vic	Tree, to 10 m. Soils include skeletal types derived from sandstone or granite, sandy coastal soils, including some derived from limestone, and heavier textured clay loams	XXXX	●	●		●	●	●
C. cristata	NSW, Qld	Tree, 10–20 m. Clayey soils with calcareous nodules near the surface	XXX			●	●		
C. cunninghamiana	NSW, NT, Qld	Tree, 15–35 m high. Loam over granite. Adjacent to water courses	XXXX			●			
C. equisetifolia	NSW, NT, Qld[5]	Slender, erect tree, 5–7 m high. Grey sand over sandy clay. Sand dunes, disturbed woodlands	XXXX						
C. glauca	NSW, Qld	Tree, 8–20 m high. Shelly sand over clay, along water courses, particularly brackish situations along coastal streams	XXX						
C. obesa	WA, [SA], Vic	Tree, 1.5–10 m high. Sand, clay, often in brackish or saline situations. Along rivers, creeks, salt lakes	XXX	●		●	●	●	
C. pauper	NSW, SA, Qld, Vic, WA	Tree, 5–15 m high. Red-brown soils with light-textured topsoil, sandy rises, moderate salinity tolerance	XXXX	●	●	●	●		

Note: [1] Australian jurisdictions: NSw, New South Wales; NT, Northern Territory; Qld, Queensland; SA, South Australia; Tas, Tasmania; Vic, Victoria; WA, Western Australia. Sources: anbg.gov.ai/abrs/online-resources/flora; apstas.org.au/flora.html; eflora.nt.gov.au; demo1.tmag.tas.gov.au; environment.gov.au/biodiversity; environment.nsw.gov.au/ThreatenedSpeciesApp; florabank.org.au; florabase.dpaw.wa.gov.au; plantnet.rbgsyd.nsw.gov.au; vicflora.rbg.vic.gov.au/flora; vro.agriculture.vic.gov.au: *A. campestris*, *A. hystricosa* and *A. robusta* were listed in GlobalTreeSearch but were excluded here because they are not described as being > 3 m. Conversely, *A. helmsii*, *A. lehmanniana*, *A. rigida* and *A. spinosissima* were not listed but have been included here. [3] Range: relative ranking from limited (X) to extensive (XXXX). [4] See Fig. 1 for list of Köppen codes. [5] *C. equisetifolia*: also SE Asia, Melanesia and Polynesia.

Allocasuarina acutivalvis subsp. *acutivaivis*



Allocasuarina acutivalvis subsp. *prinsepiana*



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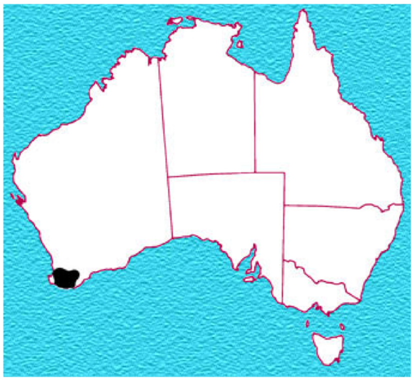
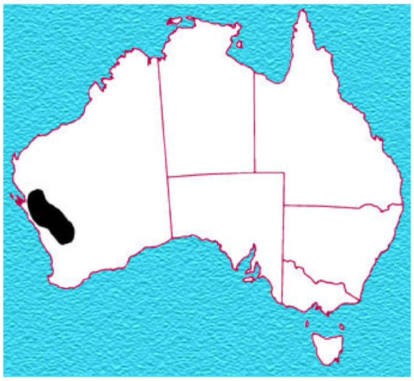
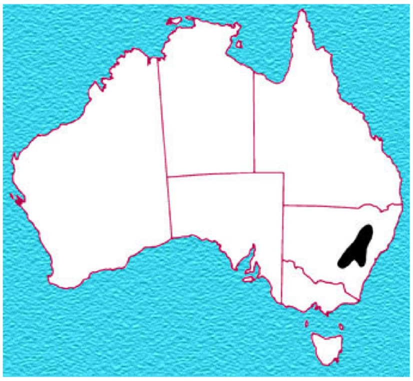


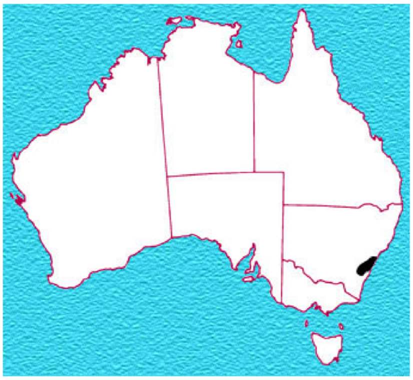
Allocasuarina decussata



Allocasuarina dielsiana



Allocasuarina diminuta subsp. *diminuta*



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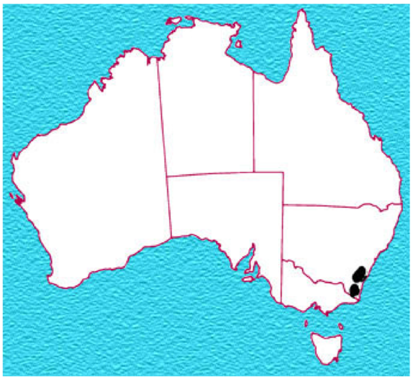
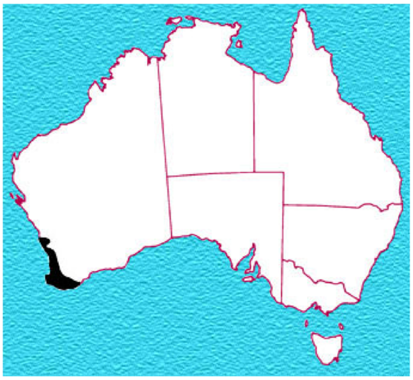
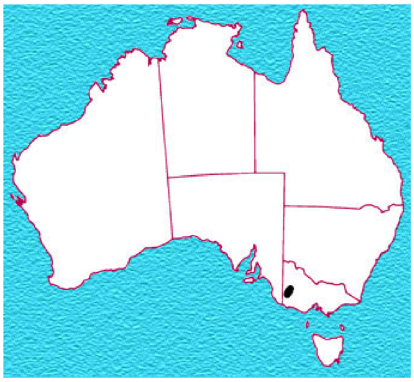


Allocasuarina diminuta subsp. *annectens*



Allocasuarina fraseriana



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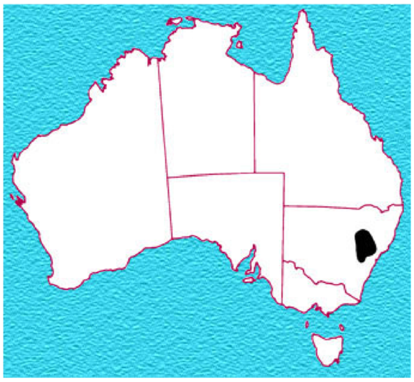

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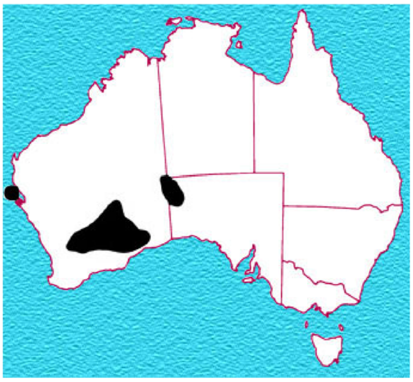
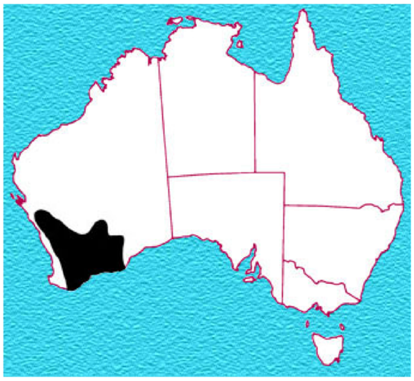
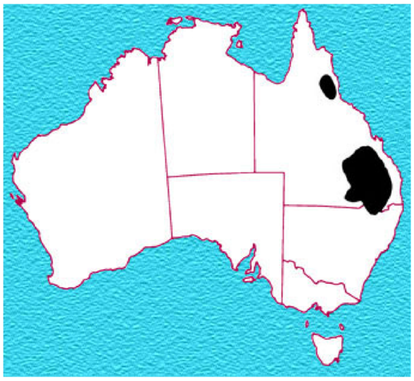


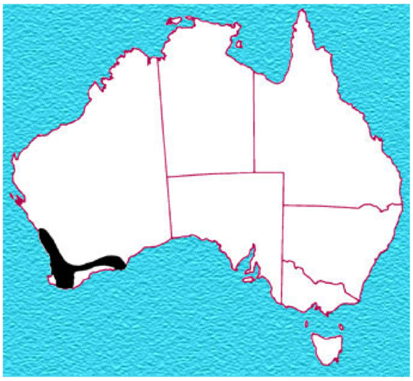
Allocasuarina helmsii



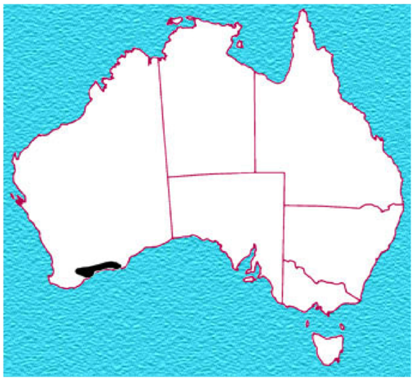
Allocasuarina huegeliana



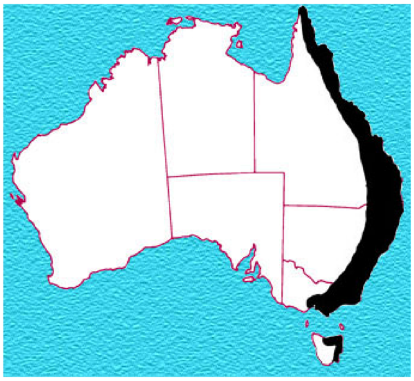
Allocasuarina inophloia



Allocasuarina lehmanniana subsp. *lehmanniana*

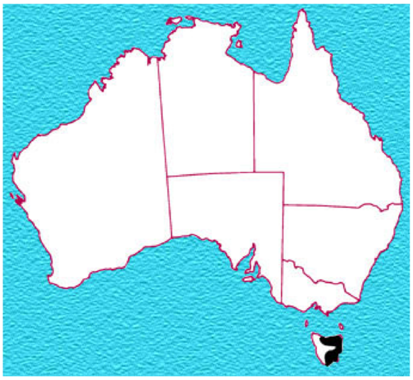


Allocasuarina lehmanniana subsp. *ecarinata*

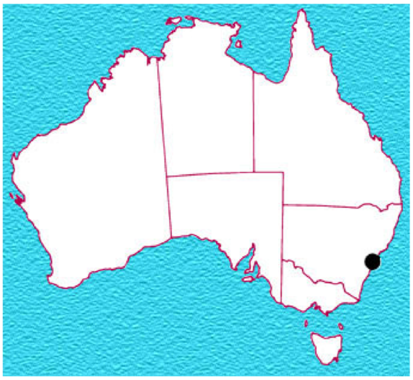


Allocasuarina littoralis

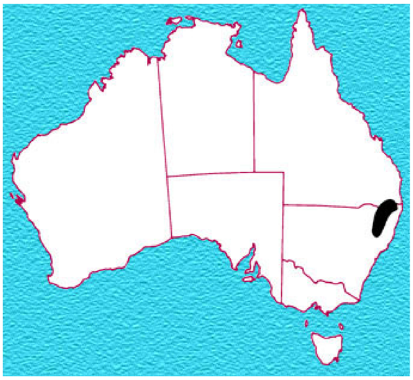
Allocasuarina luehmannii



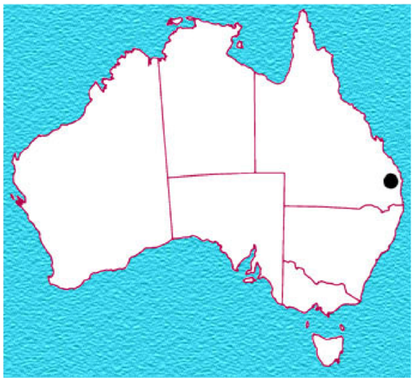
Allocasuarina monilifera



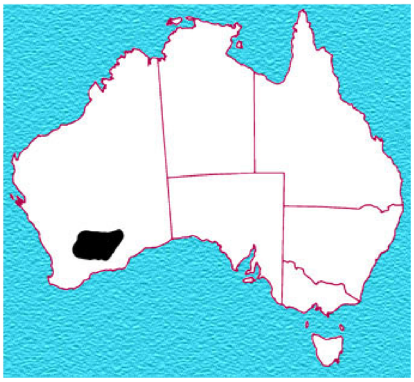
Allocasuarina portuensis



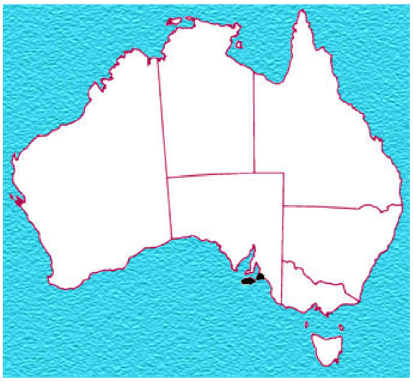
Allocasuarina rigida subsp. *rigida*



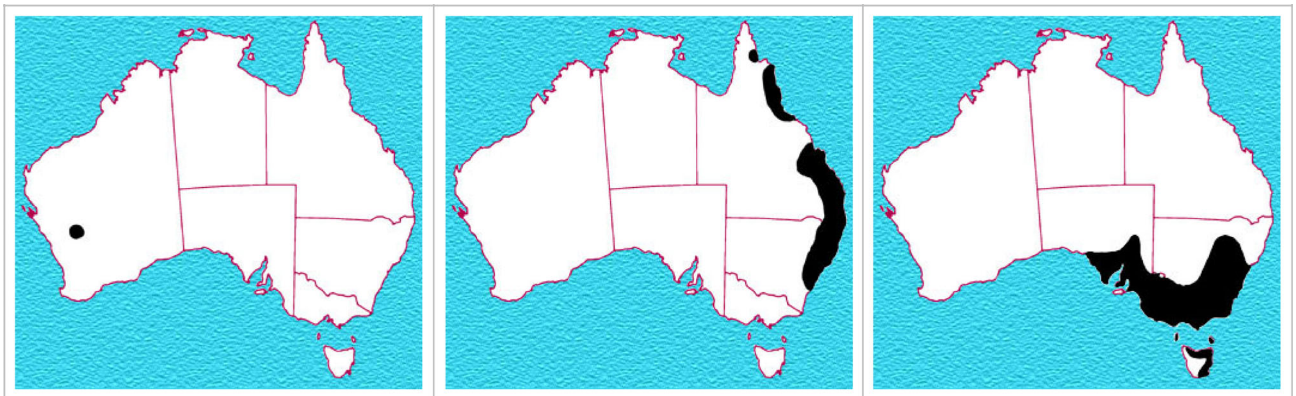
Allocasuarina rigida subsp. *exsul*



Allocasuarina spinosissima



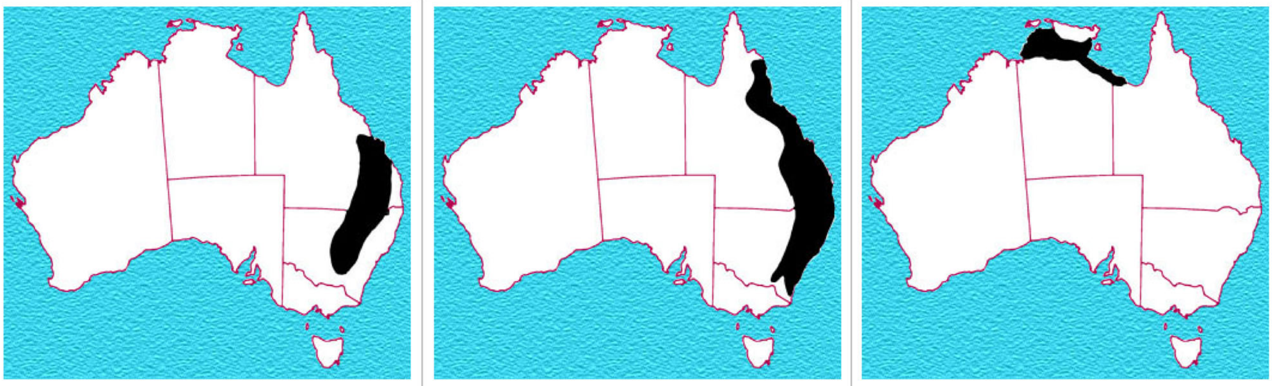
Allocasuarina striata



Allocasuarina tessellata

Allocasuarina torulosa

Allocasuarina verticillata



Casuarina cristata

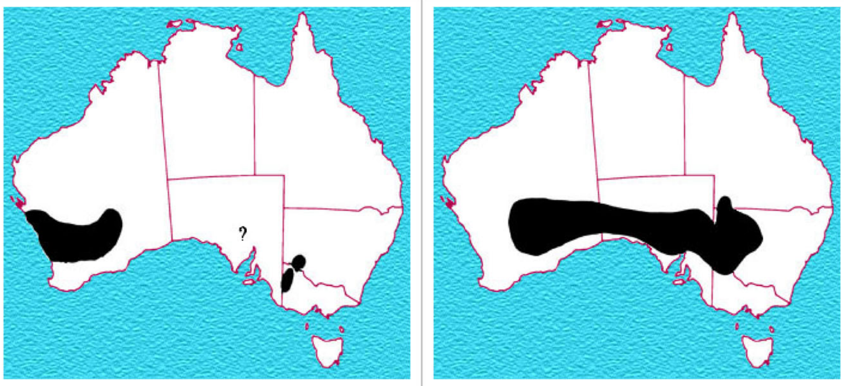
Casuarina cunninghamiana subsp. *cunninghamiana*

Casuarina cunninghamiana subsp. *miodon*

Casuarina equisetifolia subsp. *equisetifolia*

Casuarina equisetifolia subsp. *incana*

Casuarina glauca



Casuarina obesa

Casuarina pauper

Fig. 2 Australian endemic distribution of *Allocasuarina* and *Casuarina* trees and shrubs (> 3 m). Some species (viz., *A. acutivalis*, *A. diminuta*, *A. leuhmanniana*, *A. rigida*, *C. cunninghamiana* and *C. equisetifolia*) have recognized subspecies and these are shown on separate maps. A map of *A. duncanii* is not included, but it is a rare species with highly restricted distribution in south-eastern Tasmania. Source from Australian National Botanic Gardens (ANBG) website (pnid = 38582), which uses data derived from Flora of Australia volume 3[22], and is a product of Australian Biological Resources Survey, © Commonwealth of Australia.

invasive species in some subhumid to humid contexts around the world[72–74]. *A. littoralis* has, even within its native range, been described as an understory *weed* in the context of eucalypt forest decline[75]. Although the role of *Allocasuarina* spp. and the other *Casuarina* spp. as primary colonizers is not as evident, because the rate and scale of such processes in water-limited environments is more limited, particularly for woody perennials, they like other actinorhizal plants will have this capacity. Once established, the heavy litter lay and nitrogen-rich root systems of sheoaks can serve to ameliorate hostile habitats, and thereby eventually facilitate natural or assisted succession[66].

These two genera also contain significant species diversity, and presumably local population (perhaps ecotype) diversity, with 66 species from Australia, some with extensive natural distribution (Table 2; Fig. 2; Fig. 3). So the opportunity to select suitable species or accessions is considerable. One final feature of this group is they are largely free of pests and diseases especially in low-rainfall environments, although, a number of diseases of *C. equisetifolia* have been recorded in nurseries and plantation in tropical India[76].

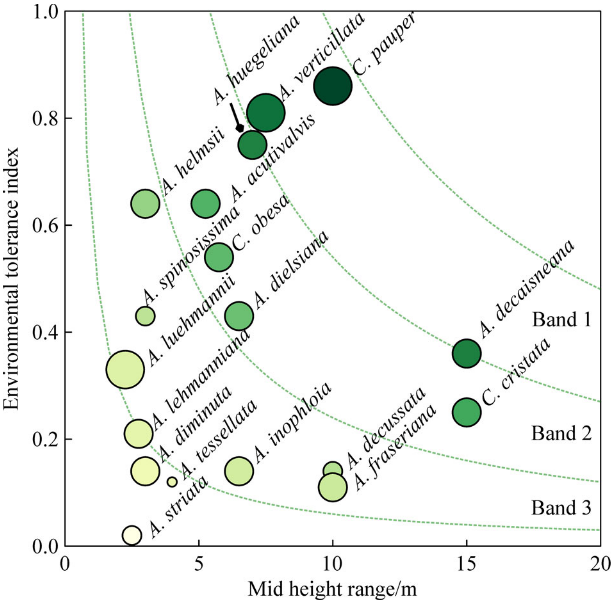


Fig. 3 Indicative environmental tolerance versus mid height range of *Allocasuarina* and *Casuarina* species that occur naturally in one or more moderate to high water- and heat-stress climatic zones (Köppen codes: BWh, BWk, BSh, BSk, Csa, Csb, see Fig. 1 and Table 2 for details). The provisional environmental tolerance index is the normalized sum of the of Köppen zones (numbered 1–6 in ascending order of stress) for those zones in which the species occurs naturally adjusted for the relative size of its range. The symbol size represents the relative range of the species (Table 2), and symbol color intensity indicative assessment priority (i.e., normalized square root of the area of the rectangle delimited by the coordinates of each point).

5.2 Assessment and deployment risks

Although an individual species, or group of species, may offer evident advantages for deployment in agroforestry or agroecosystem improvement, there will always be some risks. These risks occur in both the assessment and deployment phases, and might not even be evident as an issue for many years after deployment. When considering non-indigenous species, the most commonly perceived risk is potential invasiveness, that is, the risk the plant will naturalize and spread well beyond the intended range to cause both environmental and economic harm. For species not previously known to be invasive anywhere or even in the target context, it may take decades, especially for arboreal species, for this invasiveness to be evident. The very process of assessing exotic species also comes with a risk of concomitant introduction of associated pest and pathogens, which may themselves be invasive and spread to hosts/contexts beyond the introduced host. In addition to invasiveness, an eventual large scale deployment of a new plant species could lead to changes in fire risk, water tables and surface water collection, local flora and fauna, and even to landscapes in ways that are not readily accepted despite ecological or economic benefit.

Given that three *Casuarina* spp., and some other Australian trees, have become invasive in various countries, and some Australian eucalypts have been blamed for compromising ground water supplies and contributing to wildfires, consideration of the risks for low-rainfall-zone *Allocasuarina* and *Casuarina* species is important. There is no clear evidence that sheoaks from low-rainfall zones will present an invasiveness risk, and there are no records of them becoming naturalized beyond their native range. Likewise, the risk is low because of their relative freedom from pest and pathogens, and their taxonomic separation from the flora of similar climatic regions lowers the risk in this aspect. The Betulaceae is the most closely related family, but consist of largely temperate zone species. Sheoaks have low flammability[77] so are not prone to canopy fires, and their litter burns slowly and the suppression of understory grasses means that can be used to prevent the spread of grass fires[66,78]. Being large shrubs to small trees they are also unlikely to have aggressively adverse effects on ground water, but also, this risk can be managed through the scale and location of deployment. So on balance, this group appears to be free of major risks, but any project to assess or deploy members of this group should regularly reassess this perception.

6 *Allocasuarina* and *Casuarina* spp. selection for assessment

If the proposition presented above is accepted, it would be ill-focused and impractical to attempt to collect and assess all 66 species. So, here a method to restrict this initial selection has been applied. First, only species that grow to 3 m or more were included, which reduced the number to 23 *Allocasuarina* spp. and 6 *Casuarina* spp. (Table 2). The cut-off of 3 m was chosen because in an agroecosystem context with grazing animals, it is considered that this would allow for persistence under light to moderate grazing. Although smaller shrubs can be useful (if not essential) in ecosystem rehabilitation[79], here the focus is on the more arboreal species. Next, the native distribution of the species was obtained from online sources (Fig. 2), ranked on a relative scale and used to determine occurrence in the six water-limited Köppen climatic zones in Australia (Fig. 1; Table 2). Table 2 also provides information on plant statue and the common soils conditions in which they grow.

An indicative (semiquantitative) environmental tolerance index was calculated and used to help further restrict the range of species to those with the greatest potential suitability for Central Anatolia. The six Köppen zones were given a rank of one to six from the least to greatest degree of heat- and water-stress. For each species, the sum of these ranks for the zone in which they occurred was averaged and normalized, and then their normalized relative range used as a further adjustment factor. This process was based on an assumption that species with wider occurrence will tend to be more environmentally tolerant than those with narrower distribution. This tolerance index is plotted against the mid height range (Fig. 3), but only for species that occur in at least one of the six high-stress Köppen zones. *C. cunninghamiana* was excluded because it only occurs along inland watercourses in arid zones. The relative range is indicated by the symbol size. The mid height range is used as a simple surrogate for plant growth potential. However, although the positioning of the species in these two dimensions gives some indication of their relative merit, this has also been integrated and displayed as the increasing color intensity. The square root of the area of the rectangle prescribed by the coordinates of the species was used to allow grouping of species, taking into account contributions of both the tolerance index and height. This parameter is considered to be an indicator for comparative priority for assessment. Three bands of equivalent intensity have been added to the figure.

Using this analysis, *A. verticillata* and *C. pauper* (Band 1) are given highest priority, and *A. acutivalvis*, *A. decaisneana*, *A. dielsiana*, *A. huegeliana*, *C. cristata* and *C. obesa* secondary priority (Band 2). However, this relatively simple approach has its limitations. For example, mid height range is an indicator of accumulated growth not growth rate, *per se. A. decaisneana* grows to trees of remarkable size given the harshness of their desert environment, however, the large specimens are considered to be quite old and young specimens slow growing in nature, presumably because it has a particular adaptation for extreme aridity involving the allocation of a considerable proportion of photosynthates to root development; roots can grow 10 m deep[24,66,80]. So perhaps it might not be considered as particularly suited for early use in ecosystem restoration. Nevertheless, with trickle irrigation it is reported to reach 4 m within 6 years in a hot, arid environment, so its performance in less arid environment might be better than expected.

Otherwise, the species indicated in Bands 1 and 2 are those with moderate or higher growth potential and/or clear environmental tolerance over a moderate or higher range of water-limited environments, and most have some tolerance to either alkaline or saline soils. So the analysis appears to provide a reasonably starting point. Other factors that will need to be considered in advance or during the initial *in vivo* assessment include (1) potential availability of sufficient quantity of seed for future field-scale evaluation, (2) *Frankia* inoculum availability and compatibility, (3) ability to establish and grow in the common soils of the target area (in this case the calcarious and often shallow soils of Central Anatolia; Çullu et al.[81]) and root system performance in these soils, and (4) capacity to tolerate conditions beyond those in their native ranges (in this instance lower winter temperatures and snow cover).

7 Recommendations

The potential of *Allocasuarina* and *Casuarina* for wider economic and ecosystem has been recognized for many years. The first international *Casuarina* workshop[24], in which the current author was a participant, recommended more systematic research across a wider range of taxa and provenances, but had a focus on silvicultural applications in humid to sub-humid environments. It was noted that at that time many species, especially from Western Australia, had not been collected, studied or tested for use beyond their native range[24]. Although there have been some efforts to address this gap, progress has been limited, and Mediterranean to semi-arid agroecosystems have received little attention. In response, Ganguli and Kennedy[66] have made a renewed call for wider evaluation and adoption of *Allocasuarina* and *Casuarina* in agricultural systems. So, joining these voices, again a call is made here for consideration of the *Allocasuarina* and *Casuarina* species as potentially useful contributors to agroecosystem improvement, and specifically so for Central Anatolia, a region with an unquestionable need for such protection and improvement as the threats of climate change become a reality. This assessment needs to commence with research cognizant of the biology of the plants[82], and soil and climatic factors of the target region to ensure that initial efforts are not frustrated, and a recognition of the extended time needed for such an endeavor to achieve demonstrable gains.

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Compliance with ethics guidelines Ian T. Riley declares that he has no conflicts of interest or financial conflicts to disclose.

This article is a review and does not contain any studies with human or animal subjects performed by the author.

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