Pak. J. Weed Sci. Res., 18: 187-197, Special Issue, October, 2012

INVASIVE PLANT THREATS AND PREVENTION APPROACHES IN THE ASIA-PACIFIC REGION AND UNITED STATES

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INTRODUCTION

Many countries have developed noxious or invasive species lists of plants that are economically or ecologically damaging to both agricultural and environmental areas. These lists, however, rarely include species not yet present in the region, but with the potential to cause significant harm. The challenge in many prevention programs is to anticipate what new weeds are likely to invade a region or country, how to assess their potential impact, what areas provide suitable habitat under current and predicted climate change scenarios, where is their most probably pathway of entry, and how to prevent their introduction and establish. It is far easier for countries or regions to determine potentially harmful weeds by comparing and evaluating weedy and invasive species in other regions of the world with similar climates. This can include plant species that have been problematic for several years and are globally widespread, or plants that are newly established in only one region of the world. A far more difficult task, however, is to determine the potential weedy species that have yet to become problematic in any area of the world. In this paper, I initially compare the weedy and invasive species in Australia and California and then outline a process for determining new potentially invasive species and preventing their possible entry into a region.

Comparison between Noxious and Invasive Weeds of Australia and California

Weedy and invasive plants in Australia and California were introduced from a variety of regions in the world. Using the *Aquatic and Riparian Weeds of the West* and *Weeds of California and Other Western States* (DiTomaso and Healy 2003, 2007) and the *Noxious Weeds of Australia* (Parsons and Cuthbertson, 2001) to determine the origin of weedy species in the two regions, it is clear that harmful plants have been introduced from continents around the world (Table-1). The percentage of weedy or invasive plants originating from Africa, Asia, and Australia and New Zealand were very similar between California and Australia. However, more than twice as many noxious weeds of Australia originated from Central and South America

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compared to California. Conversely, far more weeds in California originated from Europe and North America compared to Australia.
In comparing the most recent lists of weedy and invasive species between the two regions, there was a considerable number of species that were weedy or invasive in both Australia and California (Table-2). Of the 396 noxious or listed species in Australia (http://weeds.gov.au/), 41% of these plants are either naturalized or weedy in California. When considering the 305 species of noxious or invasive weeds in California (Cal-IPC 2006 and http://www.cdfa.ca.gov/phpps/ipc/weedinfo /winfo_list-synonyms.htm), 31% of these species are also listed as weedy in Australia. The species considered noxious or on the invasive inventory in both regions are listed in Table-3.

Table 1. Origin of weeds in Australia and California.

Origin of weedy or invasive species	Australia	California
	Percent of total	
Africa	16	13
Asia	9	6
Australia and New Zealand	7	6
Central and South America	26	11
Europe	29	43
North America	13	21

Table-2. Total number of weedy or invasive species in Australia and California and the percent of species common to both countries.

Region	Total species on noxious or invasive plant lists	Percent overlap
Australia	396	41
California	305	31

Despite the overlap in weedy and invasive species between the two regions, there are a number of species that are far more important either economically or environmentally in one region compared to the other. For example, *Asparagus asparagoides, Cabomba caroliniana, Carthamus lanatus, Echium plantagineum, Emex australis, Olea europaea*, and *Tamarix aphylla* are more widespread and problematic in Australia than in California or the United States (US). It is difficult to explain why *Echium plantagineum*, which is occasionally found naturalized in California, is not as widespread as in Australia. It is possible that this species is still in the lag phase in California and may eventually spread to become a more serious problem.

Table-3. Australian noxious weeds (http://weeds.gov.au/) also listed on the California invasive plant inventory (Cal-IPC 2006) or the California Department of Food and Agriculture (CDFA) noxious plant list (http://www.cdfa.ca.gov/phpps /ipc/weedinfo). Species in bold are Australia Weeds of National Significance. Cal-IPC rankings include High, Moderate (Mod), and Limited invasiveness. CDFA lists include A (limited populations within state), B (regionally common), and C (widely dispersed in state).

Species	Cal-IPC ranking	CDFA list	Species	Cal-IPC ranking	CDFA list
Acacia paradoxa		B	*Foeniculum vulgare*	High	
Acroptilon repens (=*Rhoponticum repens*)	Mod	B	*Genista monspessulana*	High	C
Aegilops cylindrica		B	*Hedera helix*	High	
Ageratina adenophora	Mod		*Helianthus ciliaris*		A
Ailanthus altissima	Mod	C	*Hirshfeldia incana*	Mod	
Alhagi maurorum	Mod	A	*Hydrilla verticillata*	High	A
Allium vineale		B	*Hypericum perforatum*	Mod	C
Alternanthera philoxeroides	High	A	*Lepidium draba* (=*Cardaria draba*)	Mod	B
Araujia sericifera		B	*Leucanthemum vulgare*	Mod	
Arundo donax	High	B	*Ludwigia peruviana*		A
Asparagus asparagoides	Mod		*Marrubium vulgare*	Limited	
Asphodelus fistulosus	Mod	B	*Myriophyllum aquaticum*	High	
Bassia scoparia (=*Kochia scoparius*)	Limited		*Myriophyllum spicatum*	High	C
Cabomba caroliniana		B	*Olea europaea*	Limited	
Carduus nutans	Mod	A	*Onopordum acanthium*	High	A
Carduus pycnocephalus	Mod	C	*Onopordum tauricum*		A
Carduus tenuiflorus	Limited	C	*Orobanche* spp.		A
Carthamus lanatus	Mod	B	*Oryza rufipogon*		B
Carthamus leucocaulos		A	*Oxalis pes-caprae*	Mod	

Species	Cal-IPC ranking	CDFA list	Species	Cal-IPC ranking	CDFA list
Cenchrus echinatus		C	*Pennisetum setaceum*	Mod	
Cenchrus incertus		C	*Pistia stratiotes*		B
Cenchrus longispinus		C	*Prosopis* spp.		A
Centaurea calcitrapa	Mod	B	*Pyracantha angustifolia*	Limited	
Centaurea solstitialis	High	C	*Ricinus communis*	Limited	
Centaurea stoebe	High	A	*Robinia pseudoacacia*	Limited	
Chondrilla juncea	Mod	B	*Rorippa sylvestris*		B
Cirsium arvense	Mod	C	*Rubus fruticosa* (complex)	High	
Cirsium vulgare	Mod	C	*Rumex acetosella* (=*Acetosella vulgaris*)	Mod	
Conium maculatum	Mod		*Rumex crispus*	Limited	
Convolvulus arvensis		C	*Salvinia molesta*	High	A
Cortaderia jubata	High	B	*Schinus terebinthifolius*	Limited	
Cortaderia selloana	High		*Scolymus hispanicus*		A
Cotoneaster franchetii	Mod		*Senecio jacobaea*	Limited	B
Cotoneaster pannosus	Mod		*Silybum marianum*	Limited	
Crataegus monogyna	Limited		*Solanum elaeagnifolium*		B
Crupina vulgaris	Limited	A	*Solanum marginatum*		B
Cuscuta campestris		C	*Sonchus arvensis*		A
Cynara cardunculus	Mod	B	*Sorghum halepense*		C
Cyperus esculentus		B	*Spartina anglica*	Mod	B
Cytisus scoparius	High	C	*Spartium junceum*	High	C
Delairea odorata	High	B	*Tamarix aphylla*	Limited	
Dipsacus fullonum	Mod		*Tribulus terrestris*		C
Dittrichia graveolens	Mod		*Ulex europaeus*	High	B
Egeria densa	High	C	*Undaria pinnatifida*	Limited	
Eichhornia crassipes	High	C	*Verbascum thapsus*	Limited	

Species	Cal-IPC ranking	CDFA list	Species	Cal-IPC ranking	CDFA list
Emex spinosa	Mod		*Vinca major*	Mod	
Euphorbia terracina	Mod	B	*Watsonia meriana*	Limited	
Fallopia japonica (=*Polygonum cuspidatum*)	Mod	B	*Zantedeschia aethiopica*	Limited	

Olea europaea is also very limited in its invasiveness in California compared to Australia. However, this may be due to the lack of appropriate bird feeders that facilitate dispersal (Aslan, 2011). Conversely, there are a few invasive species that, while present in Australia, are far more problematic and widely distributed in California and other western states. These include, among others, *Centaurea solstitialis, Cirsium arvense, Egeria densa, Euphorbia esula,* and *Linaria dalmatica.* Interestingly, of the species considered native to Australia yet invasive in California (Table-4), none are listed as highly invasive. Conversely, of the species considered noxious in Australia, but native to California, nearly all of them are also weedy is agricultural, water use areas, or urban settings in California (Table 5). Thus, it is not surprising why they would become problematic in other countries, such as Australia, that share similar climates.

How to Determine the Next Invader

Although there are many different methods to anticipate new potential invasive or weedy species, perhaps the best initial approach is to conduct surveys of weedy species present in other countries with a similar climate. In California, through the efforts of the California Invasive Species Council, a survey was conducted of all invasive plants listed by other countries with a similar Mediterranean climate (Brusati *et al.,* unpublished data). This totalled 774 species. From this extensive list, 383 were already naturalized in California, of which 318 had been present before 1940 but had not spread or become problematic. As such, these species were eliminated from further consideration. The remaining 65 species that were more recent naturalized species in California (>1940) and the 391 species not yet naturalized in California were further evaluated. For these 456 species, 188 were sold by the nursery industry and 66 of these were currently being sold in California. Thus, the 774 initial species targeted by the survey was narrowed to 66 species that had the highest potential for introduction, establishment and invasion in the state. While there are other methods of developing such watch lists, this method was not extensively labor intensive and can serve as a good first screening of potential invasiveness for species already adapted to the climate in the new region.

Table 4. Species native to Australia and listed as invasive in California.

Species	Ranking of invasiveness (California Invasive Plant Council)
Acacia dealbata	Moderate
Acacia melanoxylon	Limited
Acacia paradoxa	State listed only
Atriplex semibaccata	Moderate
Cordyline australis	Limited
Erechtites glomerata	Moderate
Erechtites minima	Moderate
Eucalyptus camaldulensis	Limited
Eucalyptus globulus	Moderate
Myoporum laetum	Moderate

Table 5. Species native to California and weedy or invasive in Australia.

Species	Weediness in California
Cuscuta spp.	Very weedy
Cyperus eragrostis	Limited weediness
Datura wrightii	Limited weediness
Elodea canadensis	Moderate weediness
Eremocarpus setigerus	Moderate weediness
Iva axillaris	Limited weediness
*Parkinsonia aculeata**	Limited weediness
Toxicodendron diversilobum	Moderate weediness
Typha latifolia	Very weedy
Verbesina encelioides	Limited weediness
Xanthium strumarium	Very weedy
Xanthium spinosum	Moderate weediness

*Weed of National Significance in Australia.

Climate Matching under Current and Future Climate Scenarios

Once a preliminary list of potentially invasive species had been determined, it is possible to utilize climate matching models to more accurately determine areas most suitable for possible invasion. This has been accomplished with numerous other studies both regionally and globally for potential invasiveness of introduced species (Thuiller *et al.* 2005) or proposed biofuel species (Barney and DiTomaso, 2011). The California Invasive Species Council used climate matching models for 36 of their 200+ invasive plants to not only predict the potential suitable habitat within the state, but also to predict potential changes in climatic suitability under a proposed 3 C climate increase. The long-term goal, currently in progress, is to develop similar climate matching models for all known invasive plants within the state both with and without climate change parameters. This information will be used to develop a targeted Early Detection Rapid Response (EDRR) program directed to specific habitats throughout the state. A subset of potentially invasive species can be identified for each susceptible habitat in any region of the state. Similar EDRR programs can be established for plants that have the potential to be introduced, but are not currently present. It is important to note that under a climate change scenario, not all invasive plants are predicted to increase in their distribution (Figure 1). In fact, our evaluation showed that an equal number of species were expected to decrease in their distribution as were expected to increase. Overall, the average Ecoclimatic Index of the 36 species evaluated showed virtually no change (~2% increase) compared with no climate change scenario.

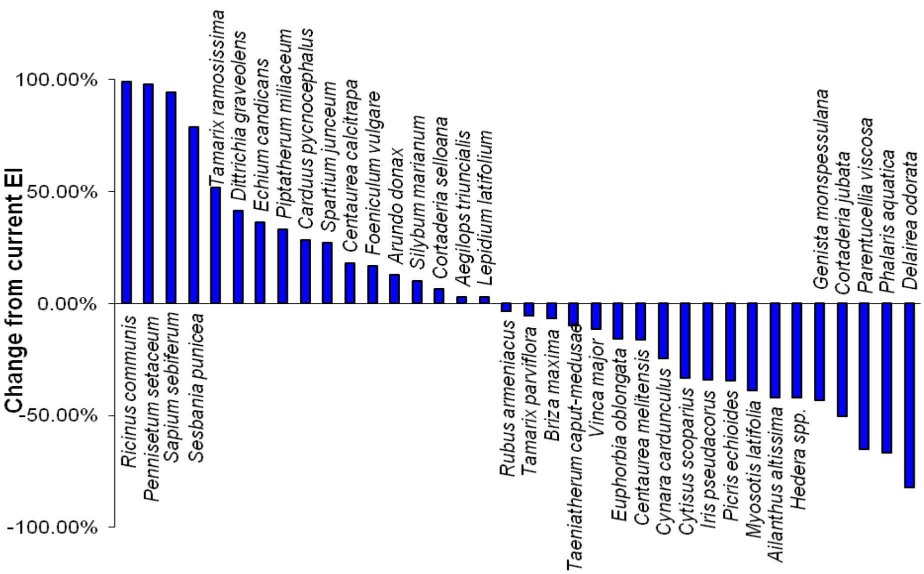

Figure 1. Predicted change in overall Ecoclimatic Index (EI) for 36 invasive plants of California. Bars above horizontal line indicate predicted increase in distribution, and values below horizontal line indicate predicted reduction in distribution with anticipated 3 C increase in temperature.

Weed Risk Assessment Models

Several Weed Risk Assessment (WRA) models have been developed, the most common of which was developed by Paul Pheloung and his colleagues in Australia (Pheloung *et al.,* 1999). The model has proved to have an overall accuracy of 90% when comparing known invasive and non-invasive ornamental plant species. Because of its high level of accuracy, it has been modified for use in New Zealand, Florida, Hawaii and other Pacific islands, and the Galapagos Islands (Pheloung 2005, Gordon *et al.,* 2008). In addition, Barney and DiTomaso (2008) applied Pheloung's model as a pre-introduction screening of three biofuel candidate crops for specific target regions. In this case, the model was used to assess whether these economically beneficial crops would pose a risk of becoming invasive. This model has been instrumental as a prevention tool for reducing the potential of introducing new invasive or weedy species to a region.

In a collaboration with the nursery industry both in California and nationwide, the California Horticultural Invasive Prevention (Cal-HIP) partnership, in its "Plant Right" campaign, is attempting to develop a third party certification process to further prevent the sale and introduction of invasive ornamental species. This is critical, as 50% of the listed invasive plants in the state originated from the ornamental plant industry. In this effort, the Pheloung model has been shown to be too conservative in predicting invasiveness and is not likely to be accepted by the industry as it lists too many "non-invasive" ornamentals as invasive. Thus, Cal-HIP in collaboration with Elizabeth Seebacher, developed an abbreviated version of the Pheloung model (Plant Right WRA) that is more specific to the industry and the US (unpublished data). This model consists of 27 questions, compared to the 49 in the Pheloung model. In an independent evaluation using the same 170 invasive (horticultural and non-horticultural) or non-invasive species (horticultural), three biologists working in separate areas of the western US ranked the species and compared the two models. The accuracy in predicting both non-invasiveness and invasiveness averaged 99% among the three biologists. In contrast, the Pheloung model was highly accurate in predicting non-invasiveness (100%), but only 80% accurate in predicting invasiveness. As such, we are now in the process of working with the nursery industry to accept the Plant Right WRA as the most appropriate tool to evaluate current nursery stock, as well as newly introduced species, in a third party certification program.

Pathways of introduction and prevention strategies

After developing a reliable understanding of the species most likely to invade a new region, their potential for invasiveness using WRA models, as well as the climatic suitability of the species to the specific regions within the area, it is critical to recognize the potential pathways for their introduction. These pathways can include natural movement, as well as accidental or intentional introduction through human activity into a new region. In Table-6, I include potential methods of introduction of new species to a region, as well as pathways of moving weedy species within the region. Each of these pathways can be designated as having a high, moderate, low or no risk of movement.

Table 6. Survey table of propagule dispersal methods and likelihood of an invasive species being introduced via that method.

Means of propagule dispersal	Risk of dispersal			
	High	Moderate	Low	None
Natural				
Water				
Wind				
Animal movement (dispersal of seed or vegetative propagules)				
Hurricanes or cyclones				
Intentional				
Agricultural				
Ornamental or horticultural				
Biofuel				
Legal human activities				
Aquarium				
Internet or mail order sales				
Illegal human activities				
Illegal entry (food or horticulture)				
Ecoterrorism				
Accidental				
Agriculture or Commerce				
Seed contaminant				
Hay contaminant				
Soil movement				
Food products				
Contaminants of nursery stock				
Commercial watercraft				
Travel or transportation activities				
Vehicle, trailer or equipment contaminant				
Ballast				
Packing materials				
Mail and packages				
Legal import contaminant (including cargo containers)				
Inadvertent human travel (internatl. & natl.)				
Recreational activities				
Recreational watercraft or vehicles				

An example of an invasive plant that is spreading rapidly around the world is

Mikania micrantha, often referred to as Chinese creeper, South American climber, bittervine or mile-a-minute. It has a high potential for causing significant economic and ecological damage in agricultural and natural areas (Manrique *et al.,* 2011). *Mikania* can be dispersed long distances by wind, as the seed contains a parachute-like pappus. Thus, the highest probability of introduction would be by wind and perhaps through hurricane activity. When populations occur in adjacent countries, states, provinces or regions special surveillance should be conducted following such natural climatic events, particularly in disturbed areas that show a high climatic suitability. This EDRR process as part of a prevention strategy would greatly reduce the probability of establishment and spread. As another example, when developing an EDRR program for species primarily dispersed long-distance through aquatic recreational vehicles, e.g., *Myriophyllum spicatum, Egeria densa*, or *Hydrilla verticillata*, inspection stations should be established at the docks of recreational areas to prevent both entry into an uninfested body of water or movement from a contaminated aquatic site.

CONCLUSION

In conclusion, by comparing the weedy and invasive flora of Australia and California it is clear that weedy plants can originate from around the globe, and though many species can be problematic in multiple regions, some species are more specific to one region of the world, while other species may still be in the lag phase in one region compared to another. Addressing the threats of invasive plant introductions is a multi-step process. It requires a complex program encompassing knowledge of plants likely to be introduced to a new region, their potential to establish, survive and spread, the predictive harmful impacts they may cause, and the most likely pathways of possible entry and movement. With this information, the probability of slowing the introduction and spread of new invasive plants to a region can be more efficient and cost-effective in the long-term.

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