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Cynthia Bramon

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Developing a Protocol for the Assessment of Invasiveness Potential of Plants in the Living Collection of the Morris Arboretum

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Title: **Developing a Protocol for the Assessment of Invasiveness Potential of Plants in the Living Collection of the Morris Arboretum**

Author: **Cynthia Bramon, Plant Protection Intern**

Date: **March 22, 2007**

Abstract:

The focus of this project is to develop assessment guidelines for evaluating potential invasiveness of plants for use in the living collection at the Morris Arboretum. Plant exploration is an important element of the mission of the Arboretum and carries with it the need for responsibility in the collection and introduction of exotic plant material. There are several respected models used for risk assessment of introduced plant material. These models focus on characteristics that are exhibited by invasive plant species. Additionally, the climatic and geographic qualities of a plant species native region are compared to the region of proposed introduction. Through a combination of research and field observations, information needed to perform these assessments can be compiled and entered into the models resulting in scores that can recommend three basic outcomes. These outcomes are accept, reject, or evaluate further. In combination with these basic outcomes, guidelines are presented here particular to use with the living collection at the Morris Arboretum. These extend the three outcomes of the risk assessment models and refer to management options that may be undertaken in order to responsibly maintain and develop not only a public display garden but an institution involved in scientific research and education.

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INTRODUCTION

Plant exploration can be a valuable tool for understanding and maintaining biodiversity in the world's ecosystems. Plants, seeds and germplasm collected are used not only to broaden the esthetic palette of gardeners by introducing unusual varieties of plant material, there are other benefits that make this work important. Wild collected plant material can be used to strengthen the genetic pool used in breeding, which can aid in offering increased hardiness. It can also expand the potential for increased resistance to devastating outbreaks of insect infestation and disease, and aid in finding cultivars that can withstand stressful urban conditions. Also worthwhile is the preservation of the germplasm of species, which due to unforeseen circumstances, may one day be endangered in the wild.

The global economy and an increased level of world trade pose difficult issues involving the importation of insect pests known only in other parts of the world that can have devastating effects when they reach our native flora. The reality is that it is unlikely that trade will be halted as a result. The challenge of monitoring ports of entry to prevent the introduction of minute insect eggs is a mountainous task. Hemlock wooly adelgid is one important threat to *Tsuga canadensis*, our native hemlock species. The potential of *Tsuga chinensis*, a hemlock of Chinese nativity, to resist outbreaks of this destructive insect is important. Growing and studying the aspects of this alternative species of hemlock may help us understand mechanisms for maintaining our own native ecosystems.

THE IMPACT OF INVASIVE PLANTS

But just as exotic insect pests can provide great injury to our native plant species, exotic plant species that become *invasive* can be equally destructive. Here it is important to understand how the term invasive is defined. Not every exotic plant that is introduced into North American horticulture will demonstrate invasive characteristics. Invasiveness is understood as a pattern of aggressive growth that out competes and displaces native plants in their own natural habitats or that disrupts the natural processes of ecosystems in a way that may irrevocably alter the native habitats that these ecosystems are composed of. A theory based on "the rule of tens" estimates that only a tenth of plant introductions are common, a tenth of those become naturalized and a tenth of those become invasive (Williamson 1996).

Buddleia davidii can begin producing seed within its first year. A single seedling can produce 3 million seeds per year. The seeds of *Buddleia* are dispersed by a variety of agents including not only wind but water (which can also help transport seedlings), humans, machinery, and on the bodies of animals.

In addition, seed banks can be formed with viable seed of some plant species surviving ungerminated for a significant number of years until the conditions are favorable. Waves of invasiveness that can occur in the intense short life of species like *Buddleia davidii* can have tremendous impact by the sheer volume of competition inundating native species.

B. davidii also resprouts readily if cut down and must additionally, and often repeatedly, be treated with an herbicide to effectively stop its growth. Other examples of aggressive vegetative patterns of spread have been seen at the Morris Arboretum in plants such as *Clematis heurcifolia* and *Leptopus chinensis*. Within just six months of inclusion in the living collection an aggressive growth pattern was observed by field staff leading to the removal of the *Leptopus*.

It is still resprouting in some areas within the Arboretum's grounds. This can have profound effects within a natural ecosystem.

Lonicera maackii can colonize and compete with natives to such an extent that it changes the structural quality of the forest. Seed, sapling and understory layers of a forest can be significantly reduced to the point of changing the makeup of the site irrevocably within 20 years. The lack of oak and hickory in the seedling and sapling layers in an oak/hickory forest could of course completely change forest composition. This can have ramifications that move beyond the canopy and down into the soil as components of leaf litter that can alter soil pH and nitrogen cycling (Luken 1996).

L. maackii invasions also tend to lead to the subsequent spread of garlic mustard populations. This herbaceous invader also alters soil qualities significantly.

Another quality of invaders is their ability to survive in difficult conditions that may include the ability to live on disturbed sites, in areas of poor soil fertility, drought, or in deep shade. These qualities should raise a flag when evaluating a plant for potential invasiveness. This aggressive competitiveness may take the form of shading out other plants, or producing thickets so dense that nearby species cannot survive, as with the alien Buckthorn, *Rhamnus frangula*. *Rhamnella franguloides*, another member of the Buckthorn family growing at the Arboretum, is showing root suckering qualities that may indicate a similar growth habit. Fruiting has been reported by field staff as good to excellent. Birds and mammals find the fruit of these species appealing and this facilitates the species' spread and survival.

Dispersal by birds and mammals is yet another area of fascinating interactions involving flora and fauna. The spread of *Malus* spp. seedlings under the canopy of oaks speaks of the role of blue jays and squirrels in dispersal. There are studies involving blue jays with relation to *Quercus* species and the patterns of distribution that are based on the behaviors of these birds (Gomez 2003). *Cephalotaxus* seems to be growing in random locations throughout the Morris Arboretum, clearly demonstrating its weedy potential, but it is unclear if this is strictly the result of seed dispersal by squirrels or if the topography of the site is affecting dispersal patterns.

The nutritional value of exotic fruits available to animals that may be the only available food source in areas where natives have been displaced is not always sufficient to meet the needs of the species. A high content of sugar versus carbohydrates will not sustain migratory birds on their long flights. *Phellodendren amurense* provides a low quality diet for birds that are attracted to it compared to the more nutritious acorns and hickory nuts (Simons, 2006). Eventually the makeup of oak/hickory forests may change because of the density and competitiveness of colonization by *P.amurense*. It has also been demonstrated that the location of nesting sites can be impacted by exotic plant invasion. Forests overtaken with *Lonicera maackii* have led to lower, more vulnerable nesting sites; this has had grave effects on some bird species because of increased nest predation (Rodewald 2006).

PREDICTING INVASIVENESS

Numerous studies have been done to try to conclude specifically what characteristics invasive plants may have in common. If one were able to define these characteristics exclusively, prediction of the risk involved with the introduction of a particular plant species could be based on those invasive characteristics and would likely be quite accurate. This has proven to be more elusive than scientists might have hoped. However there have been a few models based on risk characters that have estimated with over 80% accuracy in the categorization of plants already known to be invasive, as well as those not likely to be (Jefferson 2004, Krivanek 2006). A model developed by Reichard and Hamilton (1996) for North American woody species is shown in appendices A and B. It is based on an initial set of seven questions asked in progression with a response limited to either yes or no. The final conclusion is a recommendation to accept, reject or evaluate further.

Another successful model has been developed by Pheloung (1999) originally used for assessing weediness of plants in Australia. The model, shown in appendices C-F, is often referred to as the WRA (weed risk assessment) and has had a record for accuracy better than most. It provides a weighted score based on answers to a set of questions. A number of institutions, including the Chicago Botanical Garden (Jefferson, Avens and Ault 2004), and the Institute of Botany, Academy of Sciences of the Czech Republic (Krivanek and Pysek 2006) and an assessment in Hawaii (Daehler2004) have found that with minor adjustments (typically factoring the appropriate climate type and geography for the region that is involved in assessment) this model has proven quite useful. Use of the Reichard decision tree in conjunction with the adjusted WRA have so far been the most effective approach for evaluations found by two of the aforementioned institutions.

By using these tools in combination with continued field evaluation of introduced plants, we can begin to prevent the destructive impacts on our environment as a result of observations made only in hindsight.

It is widely accepted that the number one risk indicator is a history of a plant species having been invasive elsewhere (Reichard and Hamilton 1997). In a slightly broader context, not limited to a single character, the areas of reproduction along with seed ecology offer the most significant insight into potential invasiveness. In Pheloung's approach of looking at invasive characteristics (a highly successful model referred to as the WRA) this is under the umbrella of biology. The WRA has three categories that well describe the contributing factors. These broader areas are biogeography (under which the question of invasiveness elsewhere is looked at along with natural range, distribution, and climatic preferences), biology/ecology, and undesirable attributes such as smothering growth habit (Pheloung, et al 1999).

Within the study of seed ecology alone there is a web of interrelated characteristics. For instance, the type of seed has a lot to do with what the dispersal agent might be. In addition, the vehicle for seed dispersal is very much intertwined with seed size and abundance. A very small seed is often dependent on the wind for dispersal and is produced in large quantity. A smaller seed also has to be produced in great abundance because it cannot contain a large store of fuel reserve. It has a lower chance of surviving and thus the need for a larger quantity of seed so that the species will continue. In highly invasive plants the survival of a small quantity of viable seed is all that is necessary to assure the continued survival of a species. Invasive species often have high seed production rates, short intervals between seed production and are plants that reach reproductive maturity quickly (Reichard and Hamilton 1997, Rejmanek and Richardson1996).

To gain a better understanding of seed viability, germination rates and germination percentages, seed was collected from a small number of plants presently growing at the Morris Arboretum. Information regarding known testing methods and common germination statistics for the species of seed collected were explored in propagation references. Preliminary results of seed testing done in conjunction with this project are shown in Table 1. Not all results are presently available.

Genus/species	**Viability**	**pretreatment**	**Planted**	**Germination**	**Germination percentage**
Eucommia ulmoides	yes	cleaned, stratified	11/24/06 125 seeds	Achieved within 5 weeks	2/9/07 52% 2/23/ 07 68.8%
same	yes	uncleaned,stratified		-	-
same	yes	cleaned, outdoors		-	-
Euoynmus hamiltonianus	yes	cleaned, stratified	12/20/06 100 seeds	Achieved within 3 weeks	2/9/07 82% 2/23/07 92%
same	yes	cleaned, outdoors		-	-
Koelruetaria paniculata	yes	cleaned, scarified outdoors	50 seeds	-	-
Sophora japonica	yes	cleaned, scarified outdoors	50 seeds	-	-
Vitex agnus-castus	not clear	none outdoors	50 seeds	-	-

Table 1.

IMPLEMENTATION OF AN INVASIVE SPECIES ASSESSMENT PROGRAM AT THE MORRIS ARBORETUM

In conjunction with this assessment approach there are categories that could be used based on the indications of the surveys. Risk categories could be used to provide guidance as to where or if the species in question might belong in the living collection or on in a broader context be made available for the public at all. Species such as *Cephalotaxus* that is exhibiting weedy qualities, but because its reproductive cycle takes two years to complete and it is readily removed while young, would be a good candidate for continued evaluation. Certainly a species like *Rhamnella franguloides*, closely related to known invasives, would warrant at minimum continued evaluation and potentially removal.

Cedrela sinensis, started at the Arboretum while it was still a private estate with the planting of one tree in the late 1800's is now a grove of 26 trees, either seeded in or reproduced vegetativly by the one original plant. This grove is located in a highly managed area. It would not be responsible to distribute this tree to private landowners only to have it wind up on woodland's edge. Seed studies should be done to test what potential seed dispersal might have over a broader area. This plant would fall into the category of restricted movement until further evaluations would warrant either its continued management and presence as part of scientific collection or its removal if it's potential to invade demands that response.

Based on the use of Reichard's decision tree, Buddleia *davidii* should be removed from the living collection as soon as possible. After choosing either of two possible paths on the decision tree, the results consistently arrived at reject as the concluding decision. The invasive qualities that we now are aware of demand nothing less than removal (ISSG 2006). *Koelruetaria paniculata* has produced numerous seedlings as the Arboretum. It has been officially listed as invasive in the State of Illinois, by a local park group in the town of Murraysville in western Pennsylvania, and in North Wales, Australia (Swearingen 2006, Bushland Friendly Nursery Scheme 2004). Phasing out this plant at the Arboretum would certainly be warranted.

Sterile hybrids based on polyploidy (the number of chromosomes pairing to produce fertile or sterile plants) should be used with caution (Reichard and Hamilton 1997) and interpretation to the public so there is an awareness that not all cultivars of some plants are non invasive such as the hybrids of *Hibiscus* or *Lagerstroemaria.* Dioecious plants such as *Phellodendren* spp. could be managed by removal of females so that the potential to reproduce by seed is eliminated.

One trying aspect of evaluation is the time lag involved from the time of introduction to the time plants become invasive (Binggelis 2001). Part of this difficulty comes with a general lack of documented information on some plants from various regions of the world (Pauchard 2004). One of the most elusive qualities to find adequate information on is the age of reproductive maturity or the length of the juvenile period (Reichard 1997). It may involve many years, but holding a plant in evaluation until this age is reached is an important aspect to the process of eliminating risky introductions. The five main categories would be as follows: Continued Evaluation, Restricted Movement, Remove or Do Not Introduce, Interpret, and Accept.

Morris Arboretum field staff woody weeds list

*Acer negundo**	*Acer palmatum*
*Acer rubrum **	*Aesculus parviflora*
Buxus spp.	*Cephalotaxus spp.*
Cercis chinensis	*Clematis heurcifolia*
Cornus kousa	*Eleagnus pungens*
Euoynmus alata	*Euoynmus hamiltonianus*
*Fraxinus pennsylanica **	*Hedra helix*
Ilex opaca native	*Koelruetaria paniculata*
Leptopus chinensis	*Ligustrum spp.*
Lindera obtusiloba	*Liriodendron tulipifera**
Malus spp.	*Metasequioa spp.*

CONCLUSION

As far as implementing a process of evaluation and analysis on a practical level, the Morris Arboretum is blessed with a talented and keenly aware horticultural staff. Documenting observations and the reporting/collecting of information needed to plug into the risk assessment models could readily fit into the activities that the field and research staff undertake and would not involve a massive restructuring or reorganization. The ongoing collation and input of information needed to run species through the models and maintain and update records would undoubtedly require additional resources. The commitment to evaluate introductions should also be done in retrospect and plants currently in the living collection should be assessed with documentation brought up-to-date, ratings applied and recommendations based on that information implemented.

By signing the St. Louis Voluntary Codes of Conduct, the Morris Arboretum has, along with a handful of other botanical gardens and arboreta, shown it's commitment to stewardship of earth's plant treasures both in the garden as well as in their native environments. It is in that spirit that development of a protocol for use at the Arboretum to help reduce and deter unintentional invasive plant introductions moves forward. Participation in plant exploration is an important part of the mission of the Morris Arboretum. Within that mission lies an ethic of responsibility that the Arboretum wishes to uphold.

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APPENDIX A: REICHARD CHARACTERISTICS SPREAD SHEET

APPENDIX B REICHARD'S DECISION TREE

Does the species invade elsewhere, outside North America?

No | Yes

known seed sterility? | family or genus already strongly invasive in NA?

Yes | No | No | Yes Reject

spread quickly vegetative means? | native to parts of NA other than region of proposed intro? | native to parts of NA other by than region of proposed intro?

Yes further analysis | No accept | yes | no | No reject | Yes further analysis

spread quickly by vegetative means? | juvenile period less than 5 years (Trees) less than 3 years (shrubs) or grow very rapidly in first two years?

No Accept | Yes further Analysis | No | Yes

does it reproduce quickly vegetativly | does it reproduce quickly vegetativly

No | Yes | No | Yes

is it in a family or genus with species already strongly invasive in NA? | does seed require pretreatment for germination? | does seed require pretreatment for germination? | reject

Yes further analysis | No accept | Yes | No | Yes | No

family or genus with species already strongly invasive in NA? | further analysis | reject

Nφ, accept | further analysis

APPENDIX B-1

Acer palmatum

Does the species invade elsewhere, outside North America?

No

interspecific hybrid with known seed sterility?

Yes

spread quickly vegetative means?

Yes further analysis

No accept

No

native to parts region of proposed intro?

Yes

spread quickly by vegetative means?

No Accept

Yes further Analysis

No

juvenile period less than 5 years (Trees) less than 3 years (shrubs) or grow very rapidly in first two years?

No

does it reproduce quickly vegetativly

No

is it in a family or genus with species already strongly invasive in NA?

Yes further analysis

No accept

Yes

does seed require pretreatment for germination?

Yes

family or genus with species already strongly invasive in NA?

No accept

Yes further analysis

No

Yes

does it reproduce quickly vegetativly

No

does seed require pretreatment for germination?

Yes

further analysis

No

reject

Yes

reject

Yes

family or genus already strongly invasive in NA?

No

native to parts of NA other by than region of proposed intro?

No reject

Yes further analysis

Yes

Reject

APPENDIX B-2

Buddleja davidii

Does the species invade elsewhere, outside North America?

No

interspecific hybrid with known seed sterility?

Yes

spread quickly vegetative means?

Yes further analysis

No accept

No

native to parts of NA other than region of proposed intro?

yes

spread quickly by vegetative means?

No further analysis

Yes

no

juvenile period less than 5 years (Trees) less than 3 years(shrubs), or grow very rapidly in first two years?

No

does it reproduce quickly vegetativly

No

is it in a family or genus with species already strongly invasive in NA?

Yes further analysis

No accept

Yes

does seed require pretreatment for germination?

Yes

family or genus with species already strongly invasive in NA?

No accept

Yes further analysis

No further analysis

Yes

does it reproduce quickly vegetativly

No

does seed require pretreatment for germination?

Yes further analysis

No **reject**

Yes **reject**

Yes

family or genus already strongly invasive in NA?

No

native to parts of NA other by than region of proposed intro?

No **reject**

Yes further analysis

Yes Reject

accept

APPENDIX B-3

***Cephalotaxus* spp.**

Does the species invade elsewhere, outside North America?

- ***No***
  - interspecific hybrid with known seed sterility?
    - Yes
      - spread quickly vegetative means?
        - Yes — further analysis
        - No — accept
    - ***No***
      - native to parts of NA other than region of proposed intro?
        - yes
          - spread quickly by vegetative means?
            - No — accept
            - Yes — further analysis
        - ***no***
          - juvenile period less than 5 years (Trees) less than 3 years(shrubs), or grow very rapidly in first two years?
            - ***No***
              - does it reproduce quickly vegetativly
                - ***No***
                  - is it in a family or genus with species already strongly invasive in NA?
                    - Yes — further analysis
                    - ***No*** — ***accept***
                - ***Yes***
                  - does seed require pretreatment for germination?
                    - Yes
                      - family or genus with species already strongly invasive in NA?
                        - No — accept
                        - Yes — further analysis
                    - ***No*** — ***further analysis***
            - ***Yes***
              - does it reproduce quickly vegetativly
                - ***No***
                  - does seed require pretreatment for germination?
                    - Yes — ***further analysis***
                    - ***No*** — ***reject***
                - Yes — reject
- Yes
  - family or genus already strongly invasive in NA?
    - No
      - native to parts of NA other by than region of proposed intro?
        - No — reject
        - Yes — further analysis
    - Yes — Reject

appendix C

APPENDIX D: FROM PHOLEUNG, 1995

Form B. Weed Risk Assessment Scoring Sheet

		a	b	c	d	e
Section		Question	Response [1]	Score[2]	*N* score	*Y* score
A	C	1.01			0	-3
	C	1.02			-1	1
	C	1.03			-1	1
		2.01		The response for these questions is 2 unless a climate analysis is done		
		2.02				
	C	2.03			0	1
	C	2.04			0	1
		2.05				
	C	3.01			Refer to lookup table	
	N	3.02				
	A	3.03				
	E	3.04				
	C	3.05				
B	C	4.01			0	1
	C	4.02			0	1
	C	4.03			0	1
	A	4.04			-1	1
	C	4.05			0	1
	C	4.06			0	1
	N	4.07			0	1
	E	4.08			0	1
	E	4.09			0	1
	E	4.10			0	1
	E	4.11			0	1
	C	4.12			0	1
C	E	5.01			0	5
	C	5.02			0	1
	E	5.03			0	1
	C	5.04			0	1
	C	6.01			0	1
	C	6.02			-1	1
	A	6.03			-1	1
	C	6.04			-1	1
	C	6.05			0	-1
	A	6.06			-1	1
	C	6.07				
	A	7.01			-1	1
	C	7.02			-1	1
	A	7.03			-1	1
	C	7.04			-1	1
	E	7.05			-1	1
	E	7.06			-1	1
	C	7.07			-1	1
	C	7.08			-1	1
	C	8.01			-1	1
	C	8.02			-1	1
	A	8.03			1	-1
	A	8.04			-1	1
	C	8.05			1	-1
		Total score [3]				
		Outcome [4]				
		Agricultural score[6]				
		Environmental[6]				

Lookup table for section 3.
Locate value of inputs and lookup output for each questio

	Yes to questions 3.01 - 3.05									**default**
Inputs	2.01	0	0	0	1	1	1	2	2	**2**
	2.02	0	1	2	0	1	2	0	1	**2**
Results	3.01	2	1	1	2	2	1	2	2	**2**
	3.02	2	1	1	2	2	1	2	2	**2**
	3.03	3	2	1	4	3	2	4	4	**4**
	3.04	3	2	1	4	3	2	4	4	**4**
	3.05	2	1	1	2	2	1	2	2	**2**
	No to questions 3.01 - 3.05									
Input	2.05	?	N	Y						
Results	3.01	-1	0	-2						
	3.02-3.05	0	0	0						

Procedure

1. Record appropriate responses in column b.
2. Look up score in columns d & e and reco result in column c.
3. Calculate total score.
4. Lookup and record recommendation.
5. Verify that minimum number of questions from each section are answered.
6. Compute Agricultural (A&C) and Environmental (E&C) scores: if either score is less than 1 the outcome pertains to the other sector.

Lookup table for 6.0			
years	1	2	4
score	1	0	-1

Score	Outcome
< 1	Accept
1-6	Evaluate
> 6	Reject

Section	Minimum # questions[5]
A	2
B	2
C	6
Total	10

APPENDIX E : GUIDELINES FOR ANSWERING WRA QUESTIONS

BIOGEOGRAPHY/ HISTORICAL

1 Domestication/ cultivation

1.01 *Is the species highly domesticated?*

The taxon must have been grown deliberately and subjected to substantial human selection for at least 20 generations.

1.02 *Has the species become naturalised where grown?*

This question modifies the effect of 1.01.

1.03 *Does the species have weedy races?*

This question modifies the effect of 1.01. This is particularly to deal with registered varieties under assessment.

2 Climate and distribution

2.01 *Species suited to Australian climates (0-low; 1-intermediate; 2-high)*

Climate matching is based on an approved system such as Climex or Climate, DAWA. If not available then assign the maximum score (2).

2.02 *Quality of climate match data (0-low; 1-intermediate; 2-high)*

The quality is an estimate of how complete the data used to generate the climate analysis is. If not available then assign the maximum score (2).

2.03 *Broad climate suitability (environmental versatility)*

Output from the climate matching program can be used to answer here, otherwise the response should be based on natural occurrence in 3 or more distinct climate categories, as defined by Koppen or Walter.

2.04 *Native or naturalised in regions with extended dry periods*

Rainfall in the driest quarter should be less than 50 mm.

2.05 *Does the species have a history of repeated introductions outside its natural range?*

Should be well documented. A potential weed must have opportunities to show its potential.

3 Weed Elsewhere

3.01 *Naturalised beyond native range*

Cited in floras of localities which are clearly outside of the native range. If the native range is uncertain and the known extent of naturally growing plants is within the area of uncertainty then the answer is "Don't know".

3.02 *Garden/amenity/disturbance weed*

Plant is subject to control measures in the context given (carries less weight than 3.03). If the type of weed is uncertain, then the yes response should be placed here for minor weeds particularly if the distribution is limited.

3.03 *Weed of agriculture*

Agriculture incurs a cost from control of the plant or productivity losses. This carries more weight than 3.02. If the type of weed is uncertain, then the yes response should be placed here for major weeds particularly if the distribution is widespread.

3.04 *Environmental weed*

Documented evidence that the species has altered the structure or function of a natural ecosystem.

3.05 *Congeneric weed*

One or more species within the genus are well documented serious weeds.

BIOLOGY/ECOLOGY

4 Undesirable traits

4.01 *Produces spines, thorns or burrs*

In this context, any structure known to cause fouling, discomfort or pain to animals applies. If the taxon is a thornless variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a thorny form.

4.02 *Allelopathic*

Well documented as a potential suppressor of the growth of other species.

4.03 *Parasitic*

The parasite must have a detrimental effect on the host and the potential hosts must be present in Australia.

4.04 *Unpalatable to grazing animals*

This should be considered with respect to where the plant is likely to grow and the potential herbivores present.

4.05 *Toxic to animals*

There must be a reasonable likelihood that the toxic principle will reach the animal, by grazing or contact. Many species are unpalatable and would not apply. Some species are mildly toxic but very palatable so could cause problems if heavily grazed.

4.06 *Host for recognised pests and pathogens*

The main concerns are hosts of toxic pathogens and alternate hosts of crop pathogens. A reasonable level of specificity should be applied; a pathogen of an entire family, such as takeall, should not be the basis for answering yes to an individual.

4.07 *Causes allergies or is otherwise toxic to humans*

Must be well documented and likely to occur under normal circumstances: eg. body contact or inhalation in the vicinity of the species

4.08 *Creates a fire hazard in natural ecosystems*

Should be specifically applied to the situation of species, growing in natural or unmanaged ecosystems, which have a documented growth habit that leads to the rapid accumulation of fuel for fires.

4.09 *Is a shade tolerant plant at some stage of its life cycle*

Shade tolerance can enhance the invasive potential of a species.

4.10 *Grows on infertile soils*

Australian soils are generally very infertile. Species which are known to tolerate low nutrient levels could potentially grow well here. Legumes tolerant of low soil phosphorus are a particular concern since they would also modify the soil environment.

4.11 *Climbing or smothering growth habit*

Fast growing vines and ivy's which are known to cover and kill or suppress the growth of the supporting vegetation. Plant which rapidly produce large rosettes could also apply.

4.12 *Forms dense thickets*

The thickets should obstruct passage or access, or exclude other species. Woody

perennials are the most likely candidates.

5 Plant type

5.01 *Aquatic*

Any plants which are normally found growing on rivers, lakes and ponds. These species have the potential to choke waterways and starve the system of light, oxygen and nutrients. Consequently, the score is high.

5.02 *Grass*

A large proportion of the grass family are weeds in some context. As with congeneric weed species, there is a high probability that a species from this family will be a weed.

5.03 *Nitrogen fixing woody plant*

A large proportion of woody legumes are weeds, particularly of conservation. As with congeneric weed species, there is a high probability that a species from this family will be a weed.

5.04 *Geophyte*

Perennial with tubers, corms or bulbs. This question is specifically to deal with plants that have specialised organs and should not include plants with rhizomes. Plants from this group can be particularly difficult to eradicate from a site.

6 Reproduction

6.01 *Evidence of substantial reproductive failure in native habitat*

Predators and other factors present in the native habitat can cause substantial reductions in reproductive capacity. When grown in areas without these factors, the reproductive output may be greatly increased.

6.02 *Produces viable seed*

If the taxon is a subspecies, it must be indisputably sterile. The male plants of a dioecious species should be regarded as seed producers.

6.03 *Hybridises naturally*

Documented evidence of interspecific hybrids occurring, without assistance, under natural conditions.

6.04 *Self-compatible or apomictic*

A species capable of apomixis could spread from seed produced by an isolated plant.

6.05 *Requires specialist pollinators*

Some species may require specialist pollinating agents which are not present or rare in Australia.

6.06 *Reproduction by vegetative fragmentation*

The plant must be capable of increasing its numbers by vegetative means to qualify: eg. rhizome, stolon or root fragments, suckers.

6.07 *Minimum generative time (years)*

Time from germination to production of viable seed, or the time taken for a vegetatively reproduced plant to at duplicate itself.

7 Dispersal

7.01 *Propagules likely to be dispersed unintentionally (plants growing in heavily trafficked areas)*

Unintentional dispersal resulting from human activity: plants growing in heavily trafficked areas such as farm paddocks or roadsides.

7.02 *Propagules dispersed intentionally by people*

The plant has properties which makes it attractive or desirable, such as an edible fruit, an ornamental or curiosity, and is readily collected as a cutting or seed.

7.03 *Propagules likely to disperse as a produce contaminant*

Produce is the economic output from any agricultural or horticultural activity.

7.04 *Propagules adapted to wind dispersal*

There should be documented evidence that wind significantly increases *the* dispersal range of the propagule. This includes dispersal by tumbling plants.

7.05 *Propagules buoyant*

Includes any structure containing the propagule (such as a pod) which typically becomes detached from the plant and is buoyant.

7.06 *Propagules bird dispersed*

Any fruit which is transportable and consumed by birds.

7.07 *Propagules dispersed by other animals (externally)*

The plant has adaptations, such as burrs, and/or grows in situations which make it likely that propagules become temporarily attached to the animal.

7.08 *Propagules survive passage through the gut*

The propagule are eaten by animals and remain germinable after excretion.

8 Persistance attributes

8.01 *Prolific seed production (>2000/m2)*

The criteria must be met under natural conditions and the number applies to viable seed. An estimate can be made from the seed/plant and the average size of the plant.

8.02 *Evidence that a persistent propagule bank is formed (>1 yr)*

This is to identify propagules which can persist to a second season. Greater than 1% of the seed should remain viable after more than one year in the soil.

8.03 *Well controlled by herbicides*

Well documented evidence for good chemical control of the plant, which is acceptable in the situations it is likely to be found: ie the chemical management should be safe for other desirable plants which are likely to be present.

8.04 *Tolerates, or benefits from, mutilation or cultivation*

Growth and spread of plants which can reproduce vegetatively can be enhanced by such disturbance. This should not be applied to seed banks.

8.05 *Effective natural enemies present in Australia*

A known, effective, natural enemy of the plant may or may not be present in Australia. The answer is 'don't know' unless a specific enemy/enemies is known.