Predicting weediness – what has the Weeds CRC achieved?

John G. Virtue[1,2], F. Dane Panetta[1,3] and Jason Emms[1,4]
[1] Cooperative Research Centre for Australian Weed Management
[2] Department of Water Land and Biodiversity Conservation, GPO Box 2834, Adelaide, South Australia 5001, Australia
[3] Biosecurity Queensland, Alan Fletcher Research Station, PO Box 36, Sherwood, Queensland 4075, Australia
[4] South Australian Research and Development Institute (SARDI), GPO Box 397 Adelaide, South Australia 5001, Australia
Email: virtue.john@saugov.sa.gov.au

Summary Research outcomes from the Cooperative Research Centre for Australian Weed Management on the prediction of weediness are reviewed. Advances have been made in identifying traits that distinguish high impact species for a range of environments, but these were not consistent between studies. Australia's border Weed Risk Assessment System has performed well under considerable local and international scientific scrutiny, yet minor improvements can still be made.

Keywords WRA, risk assessment, traits, models.

INTRODUCTION

Prevention is the most cost-effective weed management action and since the mid 1990s there has been considerable international development of screening systems to predict the weed potential of proposed plant introductions (Groves *et al.* 2002). Australia has been a world leader in this field, particularly with the implementation of the Weed Risk Assessment System (WRAS) (Pheloung *et al.* 1999) at Australia's border. However, improvements have been needed to address concerns such as excessive false positives (i.e. true non-weeds predicted to be weeds), lower predictive power for some taxonomic groups or life forms and the need to prioritise species post-border for early intervention programs.

The 'Weed Risk and Incursion Management' research program of the Cooperative Research Centre for Australian Weed Management (hereafter Weeds CRC) funded a range of projects from 2001–2008 seeking to improve precision in predicting the weed potential of plant species. This paper reviews the outcomes of these projects and discusses future research and development directions.

PREDICTING HIGH IMPACT WEEDS

Weed risk assessment systems are based upon an understanding of a range of factors that make some plant species more likely to invade and impact in different environments. There has been considerable research effort into predicting whether a plant species could become invasive (i.e. naturalise and spread), commonly based on reproductive and dispersal traits and invasion history (Pyšek and Richardson 2007). However, determining which of these species could also cause significant weed impacts has proven to be more challenging. Four Weeds CRC projects investigated the relationships between plant traits and level of impacts.

McIntyre *et al.* (2005) examined the traits of high- and low-impact herbaceous exotic species in subtropical grassy woodland sites under a variety of levels of grazing, soil disturbance, tree clearing, lithologies and slope positions. For grasses, four attributes were significant in determining impact: very wide lateral spread, C4 photosynthesis, tall height and large leaves. For forbs, only two attributes (large seeds and adhesion/ingestion mode of seed dispersal) were significant.

Comparative studies were undertaken on high- and low-impact environmental weeds from south-eastern Queensland (SEQ). In a glasshouse experiment a complete nutrient solution was applied at five concentrations to seedlings of 12 pairs of related high- and low-impact species (Hastwell and Panetta 2005). Plasticity in biomass accumulation did not differ between related high- and low-impact species, indicating that growth rate plasticity shows little promise as a sole predictor of impact among exotic plants. However, low-impact species had higher mortality rates at low nutrient levels than did high-impact species.

Another glasshouse experiment compared multiple plant traits across a larger number of high- and low-impact SEQ species (Hastwell and Panetta in prep.). A set of traits associated with impact was identified (including root DM, leaf area and leaf number), but had low predictive power. Traits associated with weed impact differed between plant families, with better predictive power at the family and genus, as opposed to higher, taxonomic levels.

A third project investigated predicting the level of weed impact that a naturalised legume species would have upon temperate natural ecosystems (Emms 2007). Various vegetative and reproductive traits were compared for herbaceous and woody legume species with differing levels of impact. Growth form was important, with woody species found to present a greater risk of impacts, particularly species with low seed mass. Herbaceous species were more likely to pose a weed impact if they had low specific leaf area (Emms *et al.* 2006).

Finally, a controlled experiment compared growth responses to nutrients of weedy, introduced, subtropical, aquatic species versus taxonomically related, native, aquatic species (Hastwell *et al.* 2007). Submersed, floating and emergent aquatic groups were included, with plants grown under conditions of high and low nutrient availability. There was evidence that the weedy species tend to accumulate more biomass than native species. Native aquatic plants showed little response to increased nutrients, whereas leaf area of weedy aquatics tended to increase at higher nutrients.

IMPROVING PREDICTIVE WRA SYSTEMS

The WRAS (Pheloung *et al.* 1999) has remained the pre-eminent, generic decision tool for predicting weediness of plant species, with successful testing having now been undertaken in many countries, including New Zealand, Hawaii, Japan, USA (Florida) and the Czech Republic. However, the system has been criticised for having a poor predictive rate for true non-weeds (Smith *et al.* 1999) and a substantial proportion of 'further evaluate' outcomes (Daehler *et al.* 2004). Several Weeds CRC projects have enabled a greater understanding of the performance of the WRAS. A simpler WRA system has also been developed for use by Australia's Botanic Gardens.

Caley *et al*. (2006) used the original training dataset for the WRAS for two alternative statistical approaches (logistic regression and bootstrap analysis) to examine the probability of weediness at various score outcomes. There was a low probability of weediness accompanied by a high level of uncertainty for species scoring in the 'further evaluate' range (i.e. 1–6). However, the original WRAS cutoffs for 'accept' (i.e. <1) and 'reject' (i.e. >6) were relatively robust and certain. Caley and Kuhnert (2006) also used the original training set to compare the WRAS outcome with classification and regression tree (TREE) models. A TREE model with just four of the original 49 questions in the WRAS (naturalisation beyond native range, repeated introductions outside native range, level of domestication and unintentional human dispersal) had a slightly inferior performance, but potential for large time-savings in the assessment of species.

TREE model analyses were also done on a Biosecurity Australia dataset of 1844 species weed risk assessments done since 1998 (Weber *et al.* in press). The analyses again revealed that a small subset of the WRAS variables was consistently associated with the original outcome of the assessment (i.e. accept, further evaluate or reject). A TREE model examining all of the data contained just five variables: unintentional human dispersal, congeneric weed, weed elsewhere, tolerates or benefits from mutilation, cultivation or fire, and reproduction by vegetative propagation.

The current structure of the WRAS does not clearly separate the two standard components of risk: likelihood and consequence. Daehler and Virtue (in prep.) categorised WRAS questions into these risk components using a Hawaii dataset, finding that a combination of separate likelihood and consequence scores slightly improved prediction of pest plants.

Weeds CRC staff have worked with Australia's Botanic Gardens to develop and test a simplified WRA system for categorising the potential weed risk of species held in living and seedbank collections. An additive scoring system of 10 multiple choice questions (covering weed history, competitiveness, effects on human/animal health, movement and the environment, ease of control, hardiness, reproduction and natural and human spread) was found to correctly classify 80% of both low and high weed risk taxa (Virtue *et al.* in prep.).

DISCUSSION

Comparative weed impact studies have made important contributions to the prediction of weediness through the identification of plant traits that could be utilised in weed risk assessment systems. However, important plant traits have not always been consistent amongst differing studies, either here or elsewhere (see Pyšek and Richardson 2007). Differing aims and methodologies between studies confound direct comparisons. However, it appears that a 'universal' set of weed impact traits is unlikely to exist (Hastwell and Panetta in prep.). As also mentioned by Grotkopp and Rejmanek (2007), the most promising approach to trait-based prediction of weed impacts appears to be within families and genera. Working in defined geographic and climatic regions or ecosystems also appears likely to increase predictive power.

The WRAS functions adequately as a generic system, with weediness predicted via a sufficient number of positive responses to a large set of plant trait questions. However, incremental improvements can be made. Whilst the TREE model approach offers time-savings in assessments there are some concerns.

The models derived are functions of test datasets that were not balanced in terms of species' weed status or phylogeny. The variables selected by the analyses did not cover the diversity of biology and impacts of weed species, and the Caley and Kuhnert (2006) model had no consequences component of risk. Gordon *et al.* (in press) found that the Caley and Kuhnert (2006) TREE model had poor applicability in Florida.

International studies and collaborations provide opportunities to improve the functioning of the WRAS within Australia. The second-stage decision tree of Daehler *et al.* (2004) has substantially reduced the proportion of 'further evaluate' outcomes in a range of world locations and could be readily adopted by Biosecurity Australia. A major outcome of the 2nd International Workshop on Weed Risk Assessment held in Perth, October 2007, will be internationally-agreed definitions for the WRAS questions to increase consistency and reduce uncertainty in undertaking assessments.

ACKNOWLEDGMENTS

This paper is based on and gratefully acknowledges the considerable scientific research undertaken by various Weeds CRC staff in Australia, as cited in the text.

REFERENCES

Caley, P., Lonsdale, W.M. and Pheloung, P.C. (2006). Quantifying uncertainty in predictions of invasiveness. *Biological Invasions* 8, 277-86.

Caley. P. and Kuhnert, P. (2006). Application and evaluation of classification trees for screening unwanted plants. *Austral Ecology* 31, 647-55.

Daehler, C.C., Denslow, J.S., Ansari, S. and Kuo, H-C. (2004). A risk assessment system for screening out invasive pest plants from Hawaii and other Pacific Islands. *Conservation Biology* 18(2), 360-8.

Daehler, C.C. and Virtue, J.G. (in prep.). Variable perceptions of weeds and the implications for WRA.

Emms, J., Virtue, J.G., Preston, C. and Bellotti, W.D. (2006). The importance of vegetative seedling traits in distinguishing herbaceous legumes of differing impact in temperate natural ecosystems. Proceedings of the 15th Australian Weeds Conference, eds. C. Preston, J.H. Watts and N.D. Crossman, pp. 707-10 (Weed Management Society of South Australia, Adelaide).

Emms, J. (2007). Predicting the potential impacts of new pasture and amenity legumes on temperate natural ecosystems. PhD thesis (University of Adelaide).

Gordon, D.R., Onderdonk, D.A., Fox, A.M., Stocker, R.K. and Gantz, C. (in press). Predicting invasive plants in Florida using the Australian weed risk assessment system. *Invasive Plant Science and Management*.

Grotkopp, E. and Rejmanek, M. (2007). High seedling relative growth rate and specific leaf area are traits of invasive species: phylogenetically independent contrasts of woody angiosperms. *American Journal of Botany* 94, 526-32.

Groves, R.H., Panetta, F.D and Virtue, J.G. eds (2001). 'Weed risk assessment' (CSIRO Publishing, Collingwood, Australia).

Hastwell, G.T. and Panetta, F.D. (2005). Can differential responses to nutrients explain the success of environmental weeds? *Journal of Vegetation Science* 16, 77-84.

Hastwell, G.T., Daniel, A.J. and Vivian-Smith, G. (2007). Predicting invasiveness in exotic species: do subtropical native and invasive exotic aquatic plants differ in their growth responses to macronutrients? *Diversity and Distributions* (published online).

Hastwell, G.T. and Panetta, F.D. (in prep.). Can high-impact environmental weeds be predicted from plant traits?

McIntyre, S., Martin, T.G., Heard, K.M. and Kinloch, J. (2005). Plant traits predict impact of invading species: an analysis of herbaceous vegetation in the subtropics. *Australian Journal of Botany* 53, 757-70.

Pheloung, P.C., Williams, P.A. and Halfoy, S.R. (1999). A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* 57, 239-51.

Pyšek, P. and Richardson, D.M. (2007). Traits associated with invasiveness in alien plants: Where do we stand? *In* 'Biological invasions, ecological studies 193', ed. W. Nentwig, pp. 97-126. (Springer-Verlag, Berlin and Heidelberg).

Smith, C.S., Lonsdale, W.M. and Fortune, J. (1999). When to ignore advice: invasion predictions and decision theory. *Biological Invasions* 1, 89-96.

Virtue, J.G., Spencer, R.D., Weiss, J.E. and Reichard, S.H. (in prep.). Australia's botanic gardens weed risk assessment procedure.

Weber, J., Panetta, F.D., Virtue, J. and Pheloung, P. (in press). An analysis of assessment outcomes from eight years' operation of the Australian border weed risk assessment system. *Journal of Environmental Management*.