Assessing the potential impacts of climate change on weeds in New South Wales: establishing priorities

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Summary In 2004 the Australian Government officially recognised the significance of climate change on exotic species management (both weeds and pest animals) and biodiversity conservation, with the release of the National Action Plan for Biodiversity and Climate Change (NRMMC 2004). In order to meet the objective 'to minimise the impact of invasive organisms on biodiversity in future climates', baseline information is needed on the diversity and abundance of exotic species and their current and potential distributions under predicted climate change. This information is critical for assessing and quantifying the impacts that exotic species may have on biodiversity, both now and under future climate scenarios. This paper outlines a new research project that models the potential distribution of a range of exotic plants under predicted climate change. The exotic species selected in this study primarily occur within New South Wales and south-eastern Queensland. We have categorised the species into four groups based on the level of threat posed. Three bioclimatic modelling programs (CLIMEX, BIOCLIM and GARP) coupled to a geographic information system (ArcView 9.1) will be used to predict the impact of climate change on the selected species. Information on the habitats most at risk from these species and on the native biodiversity likely to be threatened will be used to define areas where management can be focused.

Keywords Bioclimatic modelling, climate change, CLIMEX, GARP, BIOCLIM, weed management.

INTRODUCTION

The biogeographic isolation of Australia has resulted in a high level of species endemicity and diversity. In the past this isolation has acted as an effective barrier to large-scale invasion by exotic species. However, European colonisation and the advent of global trade and travel have effectively reduced Australia's isolation and have been a conduit for the accidental and intentional introduction of around 27,000 exotic plant species in 220 years (Virtue *et al.* 2004). Approximately 2800 species have since naturalised (Groves *et al.* 2003), and at least 127 are reported to pose a nascent threat to biodiversity in NSW (Coutts-Smith and Downey 2006). This threat represents an additional, and interacting stress to the threats posed by factors such as land clearing and climate change (WRI *et al.* 1992).

Anthropogenic climate change is now a widely accepted phenomenon, and the challenge emerging for researchers is to quantify and predict the impacts it will have on biodiversity at a global, regional and local scale (Vitousek *et al.* 1996, Norby *et al.* 2001). Australia's mean maximum temperature has risen by about 0.6°C and mean minimum temperature by 1.2°C (1910–2004), with average mean temperatures projected to rise by up to 6°C by 2100, relative to 1990 (Nicholls and Collins 2006). Some species are already migrating poleward or upward in elevation in response to mean annual temperature increases which effectively shift the distribution of their climatically suitable habitat (Hughes 2003, Parmesan and Yeoh 2003). Species with wide environmental tolerance, the capacity for long distance dispersal and good colonising ability are expected to be the most responsive to changing climate and may be able to take advantage of new environmental conditions. Unfortunately, these traits are characteristic of many invasive plants. With the exception of papers by Kriticos and colleagues (Kriticos and Randall 2001, Kriticos *et al.* 2003a, Kriticos *et al.* 2003b, Kriticos *et al.* 2005), research investigating the synergism between climate change and invasive species in Australia is relatively scarce.

The National Biodiversity and Climate Change Action Plan (2003–2007) (NBCCAP) acknowledges the potential for climate change to significantly increase the distribution of weed species across Australia. Objective 6 of the NBCCAP aims 'to minimise the impact of invasive organisms on biodiversity in future climates' (NRMMC 2004). Here we describe a recently initiated collaborative research program aimed at specifically addressing this objective. This work will model the potential future distribution of a range of exotic plants under predicted climate scenarios. The exotic plant species examined in this project are restricted to those species currently occurring in or expected to invade into NSW as a result of climate change and to have subsequent impacts on biodiversity.

PROPOSED METHODS

This project will use three different bioclimatic modelling programs to identify climatically suitable habitat for the selected weed species, based on both current and predicted climate scenarios.

List of priority weed species Actions in the NBCCAP identify the Weeds of National Significance (WoNS) and National Weed Alert list for Environmental Weeds as a priority. However, in total, these only account for 48 weed species (20 WoNS and 28 Alert species), whereas some 1350 species of naturalised plants occur in NSW alone (Coutts-Smith and Downey 2006). Although these two lists are important tools for motivating specific management strategies, they do not, therefore, encompass the full potential of the threat posed by weeds, particularly in the face of anthropogenic climate change. Further, the threat posed by weeds is not as dichotomous as implied by the extremes of 'nationally significant' and 'alert'. The risk is perhaps more appropriately represented as a continuum from those species present, but not yet naturalised, through to the WoNS. Here, we have categorised the exotic flora of NSW into four groups representing the entire 'risk spectrum': i) present, but not naturalised; ii) the National Alert List species; iii) naturalised, but not widespread (or sleeper species); and iv) the WoNS. In addition, a fifth category was used to assess those native species that are known to be invasive outside their natural range.

Category 1 Species present, but not naturalised – This category includes a subset of those species that occur in gardens, nurseries and agricultural trials that, based on their invasive behaviour elsewhere, pose a nascent threat upon naturalisation. Approximately 70% of the weeds in Australia are deemed to be garden escapes (Groves *et al*. 2005). An example from this category is Lily of the Nile (*Agapanthus praecox* Willd.), which poses a specific naturalisation threat in wet gullies in the Blue Mountains of NSW (CRC for Weed Management 2005).

Category 2 The National Alert List Species – These species have been identified by the Commonwealth Government as being in the early stages of establishment and having the potential to become a significant threat to biodiversity if they are not managed.

Category 3 Species naturalised, but not widespread – These species are established in NSW, but not yet widespread or considered to be WoNS. Examples include, sweet briar (*Rosa rubiginosa* L.), Mickey Mouse plant (*Ochna serrulata* Hochst.) balloon vine (*Cardiospermum grandiflorum* Sweet), African olive (*Olea europaea* ssp. *africana* (P.Mill.) P.Green) and Coolatai grass (*Hyparrhenia hirta* (L.) Stapf). Many

of these species are already widely naturalised in NSW (Botanic Gardens Trust 2006), but have not yet reached their full potential distribution.

Category 4 Weeds of National Significance (WoNS) – These 20 species were selected from a list of 71 major weed species in Australia (see Thorp and Lynch 2000). However, many of the 51 'non-WoNS' are still worthy of being considered as nationally significant and thus this fourth category encompasses all 71 species.

Category 5 Native species invading beyond their historical range – These species include native plants introduced to new areas for horticultural purposes that have become invasive in their new range, or have expanded to new ranges as a result of human activities. Well-known examples include *Acacia saligna* (Labill.) H.L.Wendl. and *Paraserianthes lophantha* (Willd.) I.C.Nielsen. The ability of some native plants to become weedy as a result of climate change may pose a similar threat to biodiversity as that posed by exotic plants.

Selection of weed species within each of these five categories was based on the following six criteria:

1. The availability of distribution data (both electronic and in print) in both the country of origin and Australia;
2. Occurrence in NSW or adjoining states (particularly south-eastern Queensland);
3. The availability of an expert/s for each particular taxon for consultation (especially for category 1 species);
4. Taxonomic validity of the species (i.e. *Lantana camara* L. was excluded as there are many cultivars in Australia and the taxonomy is currently under review);
5. A history of becoming invasive elsewhere; and
6. Known to pose a threat to the environment/biodiversity.

Collation of distribution data The output of any bioclimatic modelling exercise is in part a reflection of the quality of the input data and in recognition of this fact the collation of distribution records both in Australia and the country of origin is a key component of this project. During the last two decades considerable funding has been dedicated, both nationally and internationally, to the digitisation of herbarium records for delivery on the internet. Australia's Virtual Herbarium (AVH) project (CHAH 2006) has digitised information from more than six million voucher specimens held in the nine major herbaria, the majority of which are accompanied by a geo-referenced locality. The Global Biodiversity Information Facility (GBIF) collates species-occurrence data from worldwide natural history collections and will be used to establish the global

distribution of the species examined (Chapman 2005, GBIF 2006). However, it is clear that the use of herbarium vouchers alone cannot sufficiently quantify the actual distributional extent of a species. Artefacts in the collection data, such as the 'road-map' effect, may lead to bias. Distributions will therefore be validated against field guides and other published literature. We will also consult relevant taxonomic experts. This protocol for ground-truthing distributional profiles of invasive species in both their native and invasive ranges has been used previously (Kriticos and Randall 2001, Kriticos *et al.* 2003a,b).

Climatic scenarios   The extent to which climate will change will depend upon issues such as demographic changes, technological advances, and socio-economic developments. To account for uncertainty in future climates, potential distributions for the priority weeds will be derived from climates simulated from multiple climate models and emission scenarios. The scenarios have been selected for the year 2030 (averaged over the time period 2025–2035).

Modelling techniques   There are a number of bioclimatic models available to project potential changes in species distributions under future climates. The use of more than one model provides an indication of consistency of results and a clearer understanding of potential range changes. We will use three models, BIOCLIM, GARP and CLIMEX. BIOCLIM and GARP are both correlative statistical models while CLIMEX is a process-based model. All the models are built upon the assumption that climate is the primary determinant of the realised distribution of plant species (Baker *et al.* 2000, Kriticos *et al.* 2003a). BIOCLIM and GARP require point locations of a species' distribution together with climate data in order to determine the range of climates that the species is able to tolerate.

BIOCLIM is a correlative model that describes a species' climatic envelope as a rectilinear volume in climatic hyperspace. A species' potential distribution is identified by estimating the climate at each location and comparing it to the climatic envelope of the species. Locations with values of all climatic parameters within the range of the species envelope are classified by BIOCLIM as climatically suitable. The climatic envelope can also be projected onto climate change scenarios to identify future climatically suitable habitat. GARP uses a genetic algorithm, in which the refinement of a model for a species distribution is achieved by iterative model fitting. Rules describing the species distribution are created, then modified and tested for the accuracy with which they predict the distribution. This process continues for a set number

of iterations or until predictive accuracy no longer increases (Anderson *et al.* 2002). Once a rule-set describing a species ecological niche has been created it can be projected onto current and future climates to assess species potential distributions.

CLIMEX uses a set of 'Growth Indices' to describe the potential for growth of a species and stress indices to describe the probability of the species surviving through the unfavourable season. The CLIMEX model-fitting process involves iterations with adjustments of these parameters until the program's predictions match the species' known distribution. The parameters for a species describe the climate response functions that describe how it develops and survives on a weekly basis. After these parameters have been fitted, predictions of the potential current and future distributions of the species can be made.

While climate determines species' distributions on a broad scale, soil properties are also important. Using a Geographic Information System (GIS) (ArcView 9.1), projections of current and future distributions will be overlaid with a map of soil parent material. Projected distributions will then be refined to include only those areas that contain soil types known to be suitable for the species. The output of the three bioclimatic models will be analysed within the GIS to calculate changes in the total area and location of current and future distributions.

PROJECT OUTCOMES
Projecting areas of suitable habitat for exotic plants under future climate change is crucial for the development of long-term conservation strategies. The output of this modelling study will provide a long term perspective that can facilitate proactive management strategies for exotic plant species in both NSW National Parks and the broader landscape. The importance of National Parks as protected refugia for native species is expected to increase with climate change because these and other areas of native vegetation are likely to be essential stepping stones for those native species able to migrate with shifting climatic zones (Hannah *et al.* 2002). As weeds are known to threaten 46% of species listed under the NSW *Threatened Species Conservation Act 1995* (Coutts-Smith and Downey 2006), the development of preventative, long-term management strategies for limiting the spread of weed species is critical for biodiversity conservation in reserve and off-reserve areas.

There have been surprisingly few published studies worldwide that have attempted to predict potential future distributions of exotic plant species under predicted climate change (but see Julien *et al.* 1995, Kriticos *et al.* 2003a,b, Kriticos *et al.* 2005). Fewer of

these have attempted to use multiple lines of evidence by incorporating multiple modelling techniques and multiple climate change scenarios. This project will produce data on potential future distribution for more than 20 exotic plant species and should thus significantly expand our knowledge base.

This research will contribute projections on species listed on the National Alert and WoNS lists and thus may help to facilitate a unified State, Territory and Commonwealth cooperative response to climate change and invasive plant species. We hope that by matching the results of this project with other data sets, such as the impacts of weeds on Threatened Species in NSW (Coutts-Smith and Downey 2006), significant progress can be made towards the management of exotic plants for biodiversity conservation. In particular, we expect that the outputs should provide valuable information that could be used to instigate early intervention for particular exotic species. Early eradication has been recognised as significantly more effective and economic than measures to control widespread weeds (CRC for Australian Weed Management 2002, PMSEIC 2002) and is a key recommendation of the 2002 Federal senate report 'Turning Back the Tide' (Commonwealth of Australia 2004).

Establishing a shared responsibility across 'all of government' to climate change was identified in the NBCCAP as an important factor in arresting the threat of invasive species across Australia. In light of this, our research also aims to establish a protocol for further investigations into invasive species and climate change that can be applied by land managers at a local, state and federal level as outlined in Strategy 6.1 – 'building the capacity to predict the effects of climate change on the distribution of new and established exotic invasive organisms' (see NRMMC 2004).

Taking a preventative approach to the response of exotic plants to climate change is an opportunity for Australia to demonstrate its commitment to confronting some of the deleterious impacts of future changes in climate. We hope that the development of weed risk assessments under future climatic conditions will be a significant contribution to the conservation of Australia's native biodiversity.

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