Potential distribution of *Rapistrum rugosum* (turnip weed)

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Summary *Rapistrum rugosum* (L.) All. (Brassicaceae) is a widely distributed weed of annual crops, especially pulses, in southern Australia. With the south-west of Western Australia predicted to become drier and hotter due to climate change, the development of predictive models to determine future weed threats to the agricultural industry is essential for early intervention and to enable adaptation measures to be put in place. We measured the plant's growth in relation to temperature and used this information along with soil moisture and phenology information based on the known distribution to derive growth parameters to develop a CLIMEX model. Under a warming climate *R. rugosum* is projected to increase its distribution in the northern hemisphere, but to decrease its distribution in Australia.

Keywords CLIMEX, distribution model, climate.

INTRODUCTION

Rapistrum rugosum (L.) All. (Brassicaceae), commonly known as turnip weed or annual bastard-cabbage, is an erect branching annual that produces a turnip-like aroma when crushed (Parsons and Cuthbertson 2001). It is a widely distributed weed in southern Australia and is often found in roadsides, stock routes and winter crops (Cousens *et al.* 1994). *Rapistrum rugosum* infests winter cereals and overgrazed pastures in the Western Australian (WA) grain-belt region (Dellow *et al.* 2006). Whilst it is not considered a major weed in WA due to the lighter soil types (Dellow *et al.* 2006), it is thought that *R. rugosum* could become more widespread in WA as it can occur under hotter and drier environments than most other Brassicaceae species (Cousens and Pheloung 1996).

Rapistrum rugosum is a significant weed of pulses, but a lesser weed of cereals due to its susceptibility to phenoxy and sulfonylurea herbicides (Storrie 2006). Seeds disperse readily in the agricultural system *via* crop seed, fodder and machinery (Storrie 2006). Seedling recruitment is higher under a no-till system, supporting anecdotal evidence suggesting that this weed species may be increasing in abundance under no-till situations in southern Australia (Chauhan *et al.* 2006). It has evolved resistance to Group B herbicides in Queensland (Heap 2012).

We identified *R. rugosum* as an increasing weed risk in the future in WA under a projected climate change scenario (Michael *et al.* 2010). To further quantify the risk we developed a distribution model for *R. rugosum* using the mechanistic niche model CLIMEX, which models the potential response of a species to climate based on geographical distribution, biology and seasonal phenology (Michael *et al.* 2012a). Experiments to determine plant growth at different temperatures were conducted and these growth parameters were used to inform the CLIMEX model.

MATERIALS AND METHODS

Growth at different temperatures Seed bearing pods were harvested by hand from mature, senescing plants during November 2003 from a paddock adjacent to the Brand Highway, 6 km north of Dongara, WA (29°11'51.84"S, 114°55'10.50"E). Seeds were separated from pods by rubbing the whole pods between gloved fingers or by crushing the pods against the base of a tray. Extracted seeds were stored in a paper envelope under laboratory conditions until required for planting.

During October 2009, seeds were planted into 16 Rite Gro Kwik Pot 48 cell trays containing approximately 50 ml per cell of University of California potting mix. Average temperature in the glasshouse ranged from 12.8 to 30.3°C. Forty seedlings (thinned to one per pot) per treatment were then placed into Lindner and May environmental chambers set at temperatures of 5, 10, 15, 20, 25, 30, 35 and 40°C. Plant measurements were made using the methodology given in Michael *et al.* (2012a, b).

Distribution records and CLIMEX modelling Information on the distribution of *R. rugosum* was obtained from a wide range of online databases including www.avh.gov.au, www.tropicos.org, www.splink.cria.org.br, www.sibis.sanbi.org, www.conabio.gob.mx and www.gbif.org. Following data proofing, there were 754 valid and 239 invalid records in Australia and 3575 valid and 1893 invalid records globally.

See Michael *et al.* (2012a, b), Kriticos *et al.* (2012) and Webber *et al.* (2011) for further methodology on data proofing, development of CLIMEX models, the CLIMOND world climate dataset and selection of climate change scenarios.

RESULTS

Growth in relation to temperature Survival was inversely proportional to temperature, with plants incubated at temperatures greater than 25°C dying before the end of experiment (data not shown). Plants incubated at lower temperatures (5 to 15°C) had high survival rates that were equal to those kept in the glasshouse. Survival rates in the glasshouse were higher than those observed at similar temperatures (24.1°C) in the environmental chambers.

Maximum leaf growth rate was observed at 15°C with rates of accumulation being higher than in the glasshouse (Figure 1). Plants however grew at different rates in temperature chambers compared to the glasshouse, with more resources being directed into the production of leaves in chambers and into stems and seeds in the glasshouse (data not shown).

Taking all growth into consideration, the lower developmental threshold temperature is approximately 6.5°C and the upper developmental threshold temperature is approximately 25°C for leaves and 30°C for reproduction. Based upon 43 of the 48 individuals that produced flowers in the glasshouse, the average degree-days above a Lower Developmental Threshold value (above 6.5°C) was 717°D from emergence to flowering. The average time until flowering was 29 ± 2.8 days after the start of the experiment (and they were on average 11.7 days old at this time).

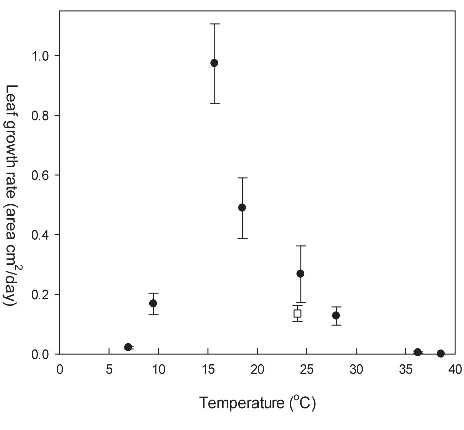

Figure 1. Leaf growth rate (± se) of *Rapistrum rugosum* under constant temperature (●) and glasshouse (□) conditions.

Distribution The distribution of *R. rugosum* includes Eurasia (where it is native) and southern Africa, coastal regions of the northern USA, parts of South America, Japan and New Zealand and temperate regions of Australia (where it was introduced) (Figure 2). Australian records for Kununurra and Alice Springs are most likely from domestic gardens and therefore not naturalised (Figure 3).

CLIMEX model Temperature and degree day parameters (Table 1) were determined from glasshouse and laboratory studies in addition to previous studies by Chauhan *et al*. (2006) and Cousens *et al*. (1994). The lower temperature threshold was set at 2.5°C and not 6.5°C as plants survived well at the latter temperature, and the lower temperature was important to enable the inclusion of northern European records of the distribution. Accepting a lower temperature threshold also changed the number of degree-days to 859. The moisture index was set to reflect the growth of a winter-growing species. Various stresses (cold, dry and hot-wet) were derived based on knowledge of the biology of the plant and by defining the regions where it was plausible that the plant was absent due to climate.

The current projection model (Figure 2) covers the known native distribution of the species, including

Table 1. CLIMEX parameter values used to model the distribution of *R. rugosum* based on the temperature experiments, native (Eurasia) distribution and phenology data.

Parameter	Values
DV0 = lower threshold temp.	2.5°C
DV1 = lower optimum temp.	12°C
DV2 = upper optimum temp.	25°C
DV3 = upper threshold temp.	30°C
SM0 = lower soil moisture threshold	0.13
SM1 = lower optimum soil moisture	0.2
SM2 = upper optimum soil moisture	1.4
SM3 = upper soil moisture threshold	1.7
TTCS = cold stress temperature threshold	-1°C
THCS = cold stress accumulation rate	-0.001 $Week^{-1}$
TTHW = hot-wet stress temp threshold	26°C
MTHW = hot-wet stress soil moisture threshold	0.7
PHW = hot-wet stress accumulation rate	0.085 $Week^{-1}$
Number of degree-days above DV0 necessary to complete one generation	859°C days

Note parameters without units are a dimensionless index of plant available soil moisture scaled from 0 (oven dry) to 1.0 (field capacity).

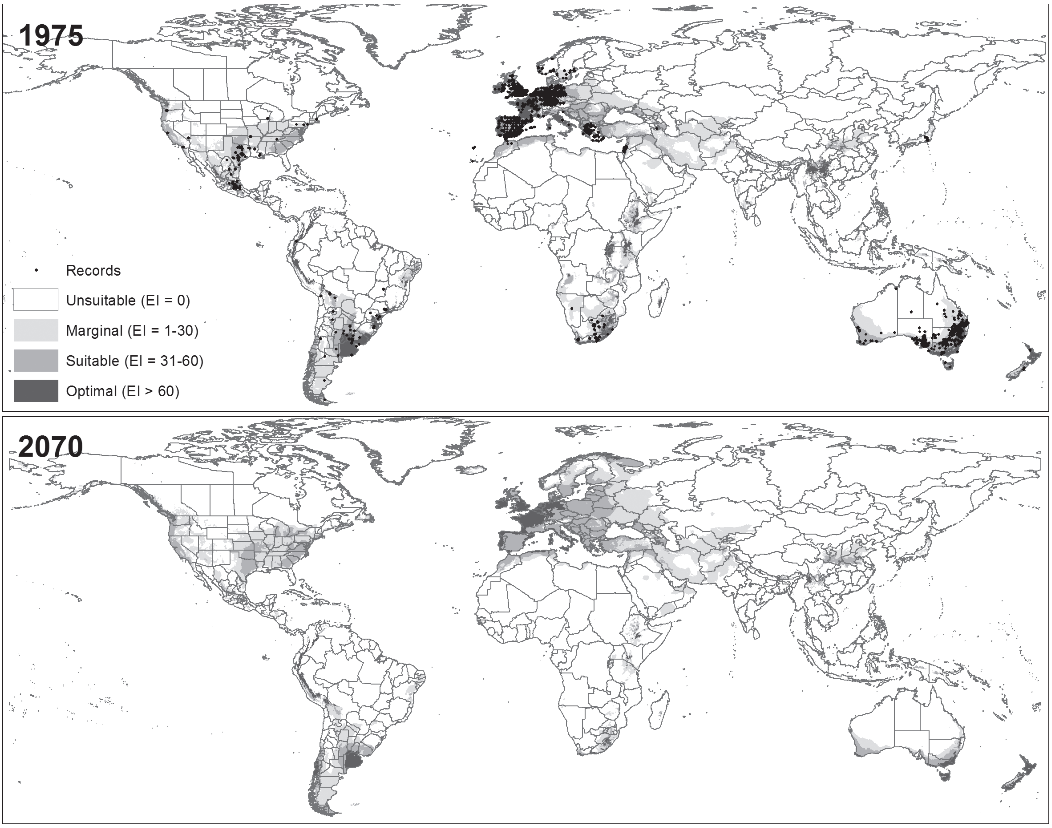

Figure 2. Known global distribution records and projected current (1975) and future (2070) climate suitability for *Rapistrum rugosum*. CLIMEX climatic suitability as shown by the Ecoclimatic Index (EI) is indicated by the changing grey scale.

southern Scandinavia and parts of Eastern Europe. It also covers the known distribution within America reasonably well, avoiding the central regions of the U.S. and South America. The model projection overlays the distribution within eastern and southern Africa, with absent collection records (except for South Africa) most likely due to missing collection data rather than unsuitability of climate.

The model projected to Australia (Figure 3) shows that *R. rugosum* is mainly suited to temperate regions of the southern and eastern parts, with the dry deserts and tropics unsuitable. The chi-squared test of association was significant (P <0.001) for both the native and Australian range.

The projected distribution under climate change shows an expanded distribution in Europe, spreading north and east into Scandinavia and Russia (Figure 2). Likewise, the projection shows an increase in North America, but a decrease in parts of South America, Africa and Asia. In Australia, the projection under climate change shows that *R. rugosum* will contract towards the coast, with suitability decreasing within the south-west of WA, southern Victoria and eastern NSW (Figure 3).

DISCUSSION

Under a warming climate, *R. rugosum* is projected to increase its existing distribution into currently cooler areas of Europe and North America, and reduce its distribution in Mediterranean-type climates and parts of South America and Asia. Whilst a reduction in suitability is projected for Australia, the species is likely to remain an issue in agricultural systems in the future due to its developing herbicide resistance and stock toxicity. With its current localised but widespread distribution in WA, an adaptation response to climate change would be to instigate or maintain quarantine and containment at the level of individual farms.

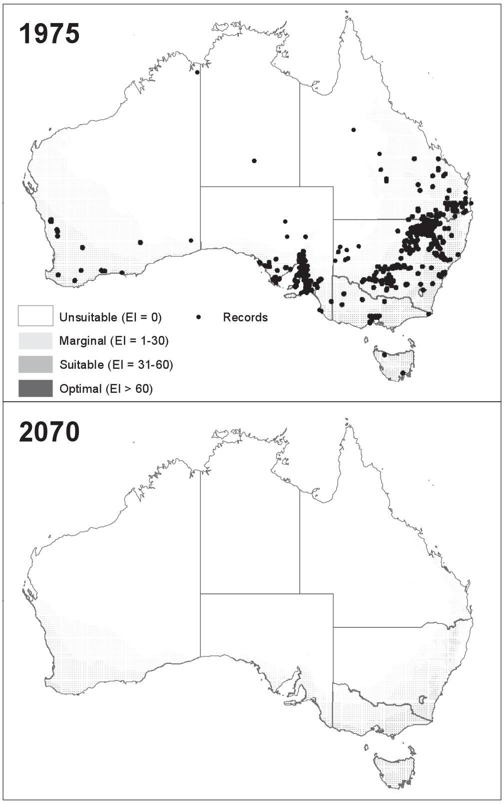

Figure 3. Known Australian distribution records and projected current (1975) and future (2070) climate suitability for *Rapistrum rugosum*. CLIMEX climatic suitability as shown by the Ecoclimatic Index (EI) is indicated by the changing grey scale.

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