Population viability analysis models for *Lantana camara* L. (Verbenaceae): a weed of national significance

Olusgeun O. Osunkoya, Christine Perrett and Chandima Fernando
Alan Fletcher Research Station, Invasive Plant and Animal Science Unit, Biosecurity Queensland, Dept of Employment, Economic Development and Innovation, PO Box 36 Sherwood, Qld 4075, Australia
Corresponding author: olusegun.osunkoya@deedi.qld.gov.au

Summary *Lantana camara* is a recognised weed of national and world-wide significance due to its extensive distribution and its impact on primary industries, conservation and biodiversity. However, no attempt to date has been made to carry out any population viability analysis (PVA) studies on the weed, despite the widely held view that PVA when done in concert with sensitivity analysis and numerical simulations could help greatly in fine-tuning management strategies for control of invasive organisms. Consequently, long-term demographic data on permanently marked individual plants (~2000 plants) across four sites in SE Queensland varying in landscape and land-use types are being collected to aid in simulation and a better understanding of the population growth of the weed. We are into the second year of this survey, and some preliminary results on seed-bank, plant fecundity, survival and growth as well as population dynamics of the weed under various management simulations will be presented. At most sites and as expected of a noxious weed, population growth rate (λ) was well above unity (across sites, mean λ = 3.449). Elasticity and numerical analyses suggest that at its expansion phase any control effort will have to jointly reduce fecundity, seed germination and seedling to juvenile/adult plant transitions by at least 95% to halt the invasion.

Keywords: Biological invasion, plant-demography, growth-dynamics, matrix modelling.

INTRODUCTION

The use of a projection matrix to formulate demographically based population viability analysis (PVA) of organisms has gained a wide currency (e.g. Caswell 2001, Osunkoya 2003, Ramula *et al.* 2008). The approach does not predict actual future population changes, *per se*. Rather, it enables a quantitative assessment of population health (increasing, stabilising or declining trend) and can suggest management alternatives that could ensure either the long-term persistence of the species (if the species deserves protection from extinction) or its demise (if the species of focus is invasive and causing ecosystem disruption). We use this approach to gain a better understanding of the population dynamics of *Lantana camara* L. (Verbenaceae) – a weed of worldwide significance. *Lantana* has been subjected to many biological, mechanical and chemical control efforts with limited success (see Sharma *et al.* 2005, Zalucki *et al.* 2007). The aims of the project are to:

(i) use a size-structure population matrix and modelling to examine vital rates of growth, survival and reproduction of *Lantana* under various landscape scenarios and
(ii) identify, from a suite of demographic parameters and with the aid of computer simulations and model predictions, the main driver/s of population growth that could then be manipulated for management purposes and/or control measures of this invasive species.

MATERIALS AND METHODS

Site description Demographic data (survival, growth and fecundity) from permanently marked individual *Lantana* plants of varying sizes (~2000 plants) were obtained from four infestation sites in SE Queensland in 2008 and again 2009. These sites (hoop-pine plantation, abandoned agricultural property (cattle farm) and two eucalyptus forests open to periodic burning and grazing, respectively) are different in landscape scenarios and land-use types. The *Lantana* populations at all sites were well established, as they contain many mature individuals, except those at the hoop-pine plantation, which has many young individuals and is thus at an initial phase of population explosion. Six months prior to the commencement of initiation of our censuses, the *Lantana* infestation within the hoop pine infestation had been flattened/clear-felled with significant soil disturbance during thinning operation of the pines by Forestry Plantations Queensland.

Population dynamics Standard deterministic approaches in demography provide the framework for setting up PVA models in most structured populations; for *Lantana*, size/stage rather than age or developmental stage was used (see Figure 1). A vector of the number of individuals in each stage category describes the population in each time step, and a matrix operates on the population vector to project the population forward in time. The elements of the projection matrix are the rates of transition between stages, and were derived from survival, growth and fecundity data in the permanent plots in the two census periods of 2008 and 2009. Growth simulations involving demographic and environmental stochasticity of 1000 iterations and 10 year steps were run using RAMAS-GIS software (Akçakaya 2005). We also performed elasticity (prospective/numerical) analyses to determine the effect of changes in elements of the matrix on population growth rate (lambda (λ)) and compared the results with standard input (i.e. field obtained values) (Caswell 2001).

RESULTS

Population growth rates and elasticity analysis The stochastic models run for each site and projected for 10 years predicted population increases for *Lantana* in three sites (hoop-pine plantation: λ = 7.80; eucalyptus forest open to periodic fire: λ = 2.672 and farm: λ = 2.328) and stability in one (λ = 0.996 – the eucalyptus forest with occasionally grazing by cattle). The projected population growth rate in the hoop pine plantation was highest – typical of the early phase of invasion.

Certain transitions are clearly overwhelmingly important in the life cycle of *Lantana*. In the expansion phase (i.e. at the hoop-pine plantation), the elements of the elasticity matrix that contributed most to the dominant eigenvalue (λ) are transition values representing seed germination (29.1%), seedling growth to medium size plants (18.9%) and seed production (fecundity) for both medium and large size plants (12.8 and 14.0%, respectively; Figure 1). These four transition values make up 75% of the contribution to λ. Similar patterns occurred in the mid-phase of invasion as exemplified by elasticity analysis of *Lantana* growth dynamics in the eucalyptus forest open to periodic fire regime and on the farm. For these sites, seed germination (19–23%), growth of seedling to juvenile/medium size plant (17.0–23.2%) and seed production (10.9–14.0%) contributed most to λ. For the *Lantana* infestation whose population growth is close to unity (i.e. the eucalyptus forest under a periodic grazing regime), adult plant survival contributed most to its stability (41, 24 and 12% for small, medium and large plants, respectively). Overall (i.e. across sites), plant growth made more contribution to the increase in population size (62%) than survival (14%) and fecundity (24%).

We used growth dynamics in the hoop-pine plantation to model the potential capability of biocontrol agents (e.g. seed/fruit feeding insects such as *Aconophora compressa* or *Ophiomyia lantanae;* see Zalucki *et al.* 2007) in halting an expanding population of the weed. We assumed population build-up of the bioagent with time, and hence increase in its efficacy as follows: 50, 95 and 99% destruction of a given life history stage of the weed. The simulation results are presented in Figure 2. None of the hypothetical simulations of biocontrol agent effects will, on its own, succeed in achieving negative population growth of the weed. Similarly, singularly reducing the other matrix elements whose contributions were deemed important to growth rate (i.e. seed germination, seedling growth and survival) did not result in λ falling below unity. However, it does appear that joint action involving at least 95% reduction in fecundity, seed germination, and seedling growth can succeed in stabilising the weed population growth rate (i.e. λ ~ 1.0).

DISCUSSION

Use of projection matrix models allows the characterisation of the present life history of a species, and the possibility of examining eventual consequences if present conditions remain constant (Caswell 2001). Thus, at all sites, except eucalyptus forest with grazing regime, *Lantana* population sizes are bound to increase dramatically provided the conditions that prevailed during the study persist. This is consistent with findings reported for invasive species in general (Ramula *et al.* 2008). From the elasticity results, it seems that in the early phase of *Lantana* invasion, growth contributed much more to λ than did survival or fecundity. Many authors have documented similar findings (e.g. Ramula *et al.* 2008, Pardini *et al.* 2009).

In the expansion phase, the seed-bank population was moderate (36% of seeds remain viable after 1 year of burial; *P1* in Figure 1), but it made little contribution to population growth, suggesting that management effort focusing on depletion of the seed bank population will be in vain. This may be (i) because of the transient nature of this element of the matrix (i.e. seed stage) as an equal proportion germinated to become seedlings in the following year and/or (ii) due to the greater contribution of growth and survival of very young seedling to λ. Thus it was no surprise that in the elasticity analysis, the dynamics of the *Lantana* population is not sensitive to the persistence of seeds in the soil (1%), but rather in increasing order to change in fecundity (27%) and germination/establishment of seedlings (67%).

Many management techniques are available for control of invasive plants. This includes physical harvesting, chemical and biological controls or a combination of the three. Due to cost and ecological-impact constraints, biological control, especially those strategies that affect adult vigour and fecundity,

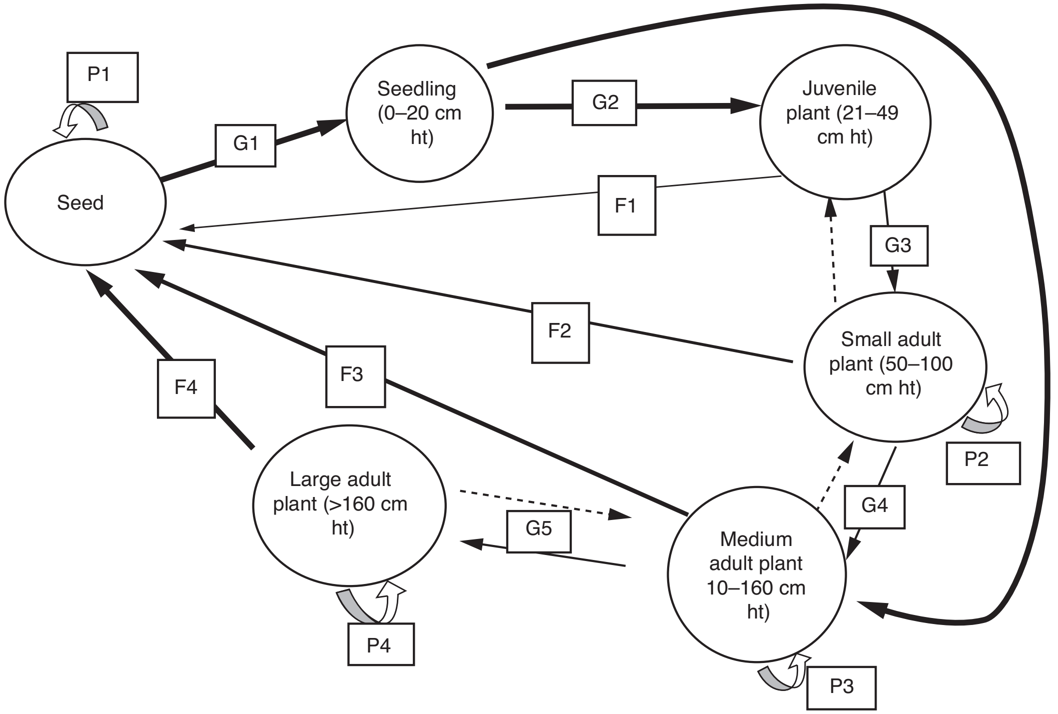

Figure 1. A stage-based life cycle of *Lantana camara* used in development of growth parameters for the weed. G_n – transition value for growth; P_n – survival value; and F_n – fecundity/reproduction value. Back transition (i.e. reduction in plant size) is possible for the reproductive adults (faint lines), especially under management regimes such as use of biocontrol agent or herbicide. Thick arrows indicate transitional values contributing more than 10% to the population growth rate (λ) in an expansion phase of the weed invasion (i.e. in the hoop pine plantation) as calculated using elasticity analysis.

has always been the more attractive option (see Zalucki *et al.* 2007), but as seen by the simulation results, it will not work in isolation. The simulations suggested that if the size of an expanding *Lantana* population is to be controlled, management effort should focus simultaneously on reduction of fecundity and decreasing the survival/growth of seedlings by at least 95% (the latter perhaps through the use of herbicide). Some studies have shown that mature plants of *Lantana* are heavily attacked in field trials by many bioagents, including a seed/fruit-damaging fly – *Ophomyia lantanae* (Agromyzidaea), a stem sucker – *Aconophora compressa* (Membracidaea) and a lace bug – *Teleonemia scrupulosa* Stål (Heteroptera: Tingidae) (see Sharma *et al.* 2005, Vivian-Smith *et al.* 2006, Zalucki *et al.* 2007). Modelling, as presented in this paper, can help to ascertain

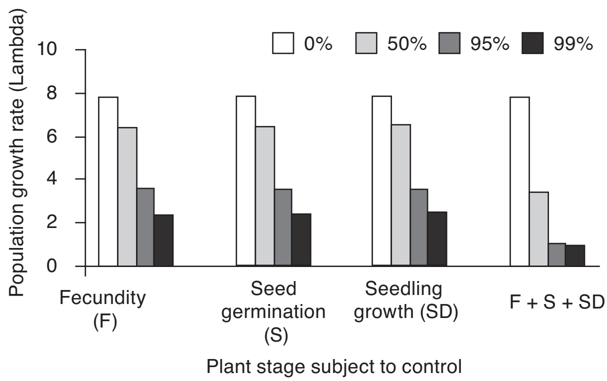

Figure 2. Summary of numerical analyses examining the effect of management intervention on population control of *Lantana* at its expansion phase, i.e. using *Lantana* demographic data from the hoop-pine plantation. All simulations involved harvesting/destruction of either 0 (control), 50, 95 or 99% of each of the three plant stages earlier identified as the main drivers of population growth rate in the elasticity analyses.

the extent of damage these biological control agents will have to exert to have meaningful results at the ecosystem level.

REFERENCES

Akçakaya, H.R. (2005). 'RAMAS GIS: linking spatial data with population viability analysis'. (Applied Biomathematics, New York).

Caswell, H. (2001). 'Matrix population models'. (Sinauer Associates, Massachusetts).

Osunkoya, O.O. (2003). Two sex population projection of the endemic and dioecious rainforest shrub, *Gardenia actinocarapa* (Rubiaceae). *Biological Conservation* 114, 39-51.

Pardini, E., Drake, J., Chase, J. and Knight, T.M. (2009). Complex population dynamics and control of the invasive biennial, *Alliaria petiolata* (garlic mustard). *Ecological Applications* 19, 387-97.

Ramula, S., Knight, T.M., Burns, J.H. and Buckley, Y.M. (2008). General guidelines for invasive plant management based on comparative demography of invasive and native plant populations. *Journal of Applied Ecology* 45, 1124-33.

Sharma, G.P., Raghubanshi, A.S. and Singh, S. (2005). Lantana invasion: an overview. *Weed Biology and Management* 5, 157-65.

Vivian-Smith, G., Gosper, C.R., Wilson, A. and Hoad, K. (2006). *Lantana camara* and the fruit- and seed-damaging fly, *Ophiomaya lantanae*. (Agromyzidae): seed predator, recruitment promoter or dispersal disrupter. *Biological Control* 36, 247-57.

Zalucki, M.P., Day, M.D. and Playford, J. (2007). Will biological control *of Lantana camara* ever succeed? Patterns, processes and prospects. *Biological Control* 42, 251-61.