Analysis of the spread of tiger pear and parthenium weed in Australia

B. A. Auld
Agricultural Research and Veterinary Centre, Orange, New South Wales 2800

J. Hosking
Agricultural Research Centre, Tamworth, New South Wales 2340

R. E. McFadyen
The Alan Fletcher Research Station, Sherwood, Queensland 4075

Summary

The spread of two weed species in Australia is described: *Opuntia aurantiaca* Lindley, tiger pear, in New South Wales and *Parthenium hysterophorus* L., parthenium weed, in Queensland. An analysis of spread in terms of rates and patterns is made. Spread pattern was described by dispersal gradients and the interaction between pattern and potential rate of spread discussed.

The rate of spread of tiger pear has decreased over the last 20 years but parthenium is spreading at an exponential rate. The potential for continued exponential expansion of parthenium is described. However in one closely monitored area where a comprehensive control programme is under way its spread rate has decreased.

The relationship of control policy development to spread and the possibility of predicting future spread using simulation is also discussed.

Introduction

Spread of plants provides the major incentive for government intervention in weed control (Menz and Auld, 1977) yet little is known of the rates and patterns of plant invasion (Auld and Coote, 1980). The faster the rate of spread the greater the divergence between private and public optimal levels of control, and the pattern of spread may dictate the optimal control strategy (Auld, Menz and Monaghan, 1979). Lack of empirical data on weed spread has been a fundamental block to the development of control theory.

Long-term surveys of two weed species in Australia are described here. These provide some insight into weed spread as well as guidelines for control planning.

Opuntia aurantiaca Lindley, tiger pear or jointed cactus, in New South Wales

Tiger pear is a spiny perennial cactus of South American origin. A low-growing species, it infests grazing land over a wide area of north-eastern New South Wales as well as small areas to the west and south. The species propagates vegetatively from stem segments and fruits. Seeds, although produced, are sterile. The spiny segments range in length from 2 to 50 cm and in diameter from 1 to 5 cm. Segments are dispersed as a result of adhering to animals and vehicles or by runoff water.

The species was first noted in New South Wales in 1883 and was regarded as a potential problem by 1911 (Maiden, 1911a, 1911b). It is a proclaimed noxious plant and landholders are obliged by law to destroy it. A special body, the Prickly Pear Destruction Commission (P.P.D.C.), supervises and assists landholders in this. The species was recently mapped from data on the P.P.D.C. files on a presence/absence basis for individual farms for the years 1938, 1958 and 1978 (Figure 1).

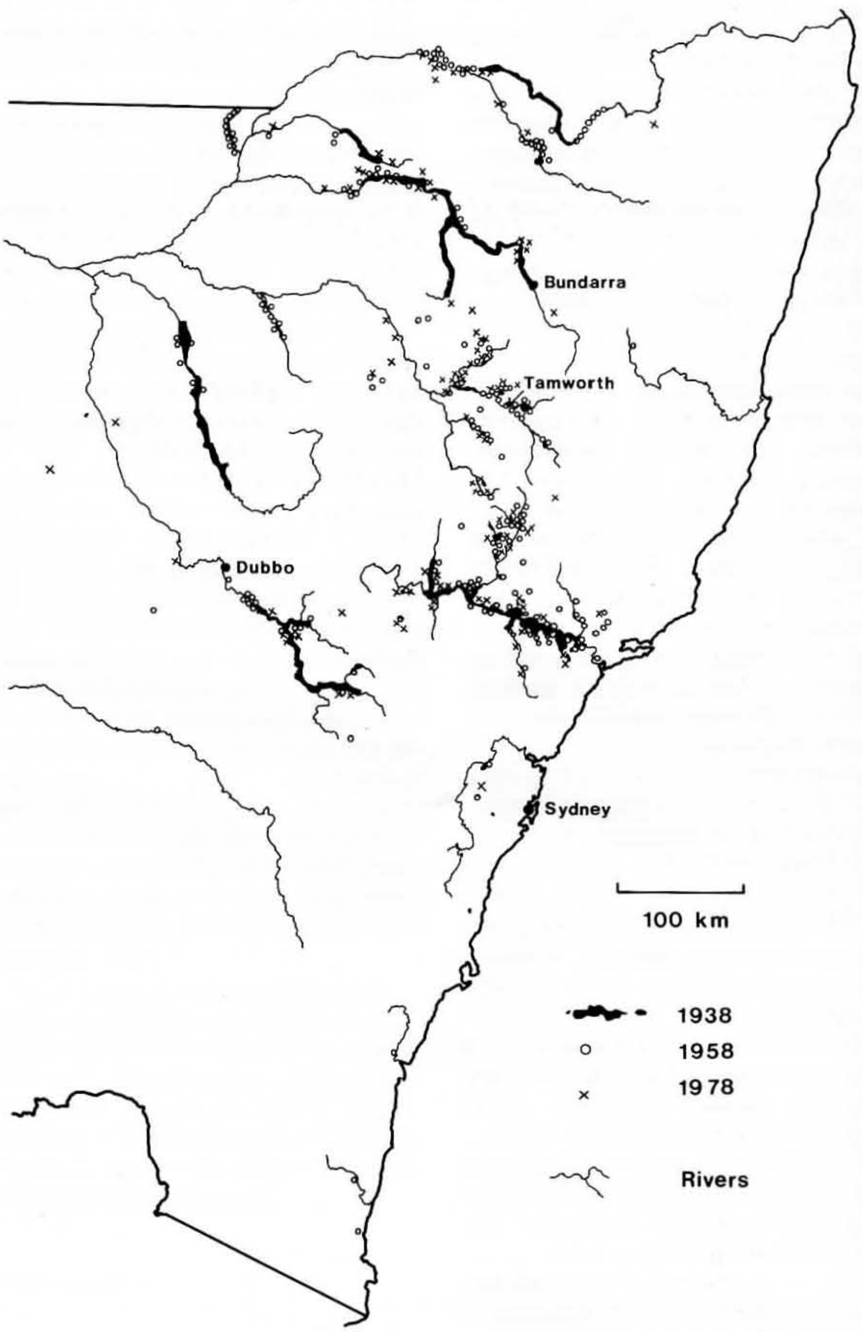


Figure 1 Spread of *Opuntia aurantiaca* in eastern New South Wales. (Symbols for period after 1938 represent new infestations; infestations recorded previously were generally still present.)

During the early 1930s cochineal insects, *Dactylopius austrinus* De Lotto, were introduced for the control of tiger pear with mixed success. Over this period the P.P.D.C. continued a chemical control campaign based on arsenic. Later in that decade a more active chemical control programme was begun and since then the P.P.D.C. has alternated emphasis from chemical to biological control as new herbicides become available and as costs of application change.

The total area occupied by properties infested by tiger pear was determined from P.P.D.C. records of occurrence on individual properties (Figure 5).

Parthenium hysterophorus L., parthenium weed, in Queensland

Parthenium weed is an exotic herbaceous annual composite. It occupies grazing land to the exclusion of other species and can cause severe allergic skin reactions in humans and livestock. Its propagule is an achene subtended by a phyllary and with two sterile florets adhering as 'wings' on each side. The size of the propagule is about 2 mm × 3 mm × 1 mm, weighing about 7×10^{-4} g. Wind transport is local and of the order of a few metres. Water transport is important and the species is also spread by vehicles and animals. Results of laboratory studies show that parthenium weed does not self pollinate (T. Armstrong, pers. comm. 1980). Thus a single isolated plant cannot result in a new infestation.

It was first identified in Queensland in 1955 (Watson, 1979). Records of its spread have been collated on a property basis by the Department of Lands (Figure 2). Although there is some doubt as to the completeness of all these records, the records for one area (45 km × 60 km) where a concerted control programme is in progress, at Collinsville (Figure 2), are known to be complete and this area was examined in detail.

Parthenium weed was introduced to Fig Tree Holding, near Collinsville, in 1972 on bulls from Elgin Downs Station. The latter was the original source of the species in central Queensland. A reconnaissance survey in 1976 established the approximate limits of parthenium weed in the area. Individual farm inspections in 1979 and 1980 were made by Department of Lands Inspectors. In these inspections the limits of the species on each property were mapped.

Like tiger pear, parthenium weed is a proclaimed noxious plant and since 1975 there has been a major attempt to control the weed by local authorities and farmers using herbicides subsidized by the State Government. The area occupied by parthenium-infested properties was determined by planimetry from 1:2 000 000 maps (Queensland) and 1:200 000 maps (Collinsville) prepared by Queensland Department of Lands.

Results and discussion

Analysis of spread

The simplest model of a spreading plant population is a circle (or focus) which increases its radius by the same distance *r* for *y* years, producing a rate of spread of area *a*,

$$\frac{\phi a}{\phi y} = 2\pi r^2 y \qquad \ldots (1)$$

A population made up of several separated smaller circles of the same total area will spread at a greater rate (Auld, Menz and Monaghan, 1979). Thus species with highest spread rates will be those which are able to increase their immediate area at a rate of $2\pi r^2 y$ and establish new foci at distances far greater than *r* away from existing infestations. Such species are those with some adaptation for long distance transport, for example having spines or as pasture or crop seed contaminants, although even poorly adapted species can be spread in hay.

Rate of spread *In vivo*, few species spreading from a single focus would be able to increase their area of occupation at $2\pi r^2 y$ because the distribution of propagules away from parent plants is usually of a negative exponential form (see below). The probability of successful establishment at distance from an infection focus increases as the population increases within the area already occupied (focus). We could therefore expect a range of initial spread rates of species, from linear forms of various gradients to exponential. For short time intervals (about 10 years) linear spread is quite likely (Auld and Coote, 1980); for longer periods it may be possible to fit an exponential model or other smooth

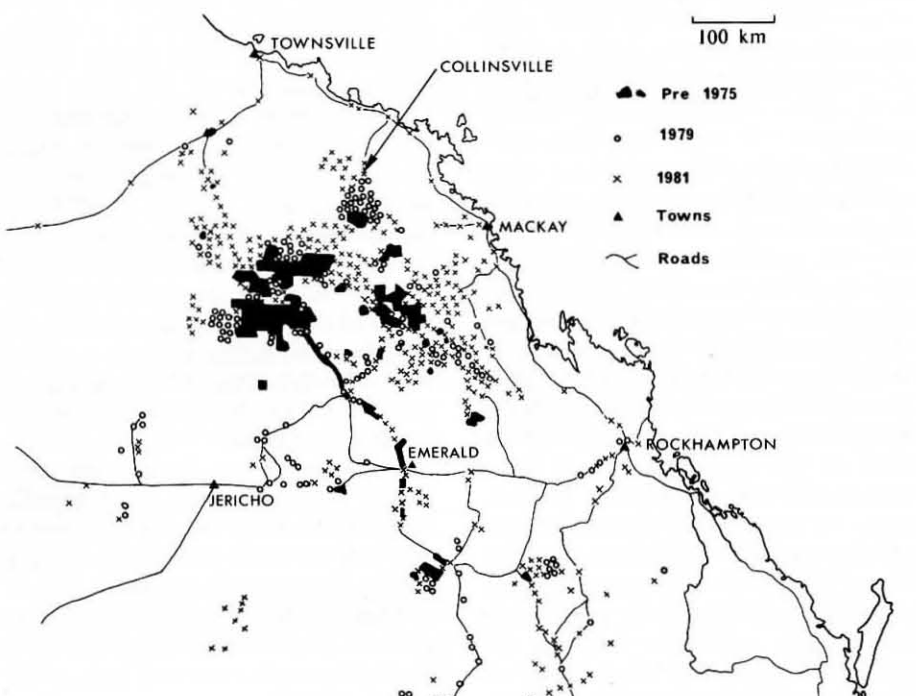


Figure 2 Spread of *Parthenium hysterophorus* in Queensland. (Symbols for period after 1975 represent new infestations; infestations previously recorded were generally still present.)

curves. Increasing rates of spread of invasive plant species are quite common (Rudenauer, Rudenauer and Seybold, 1974; Mack, 1981; Harris, unpub. data). Lacey (1957) used log plots to describe the spread of two *Galinsoga* species in England. However these data were based on total records, hence population growth rates and spread (i.e. invasion into new territory) rates were confounded. Moreover, unless the area into which a species spreading is regarded as infinite, an exponential model is ultimately inappropriate. Plant pathologists have sometimes used generalized logistic functions such as the Richard's and the Weibull functions to describe plant disease spread (Madden, 1980). The predictive value of this kind of approach to modelling spread is limited, however, by the fact that some estimate of final area infested is required as well as a number of observations during the early years of spread.

Parthenium weed has spread at an increasing rate in Queensland (Figure 3), but in the Collinsville area its rate of spread has recently declined (Figure 4).

Although data for spread of tiger pear up to 1938 are not available, the fact that it had a limited distribution in 1910 (Maiden, 1911a, 1911b) suggests the beginning of a sigmoidal form; a putative spread curve for this period (broken line) is shown in Figure 5. During 1954–58 there was a sudden increase in spread. This was the result of huge floods during 1955; the 'highest known since white settlement' in some areas (Water Resources Commission, 1980). The rate of spread has declined in recent years. Catastrophe theory (Jeffers, 1978) may provide a more rational mathematical description of sudden changes, as occurred in 1954–58, than any smooth curve. In summary, no single function would adequately describe the time course of spread of both species.

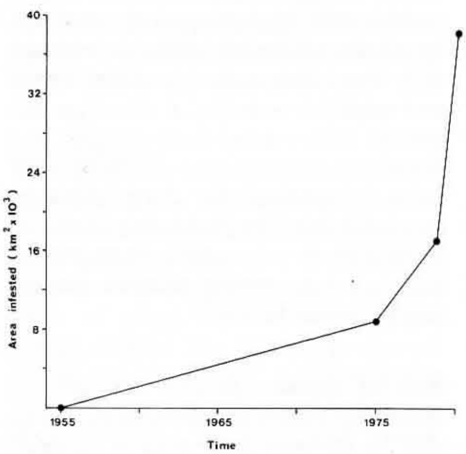


Figure 3 Time course of spread of *Parthenium hysterophorus* in Queensland.

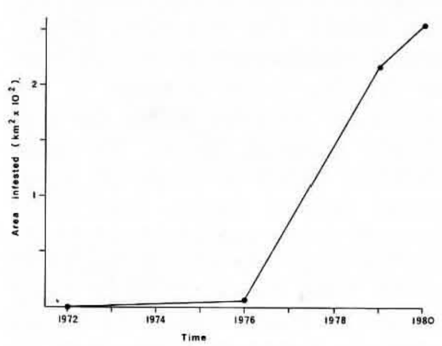


Figure 4 Time course of spread of *Parthenium hysterophorus* Collinsville, Queensland.

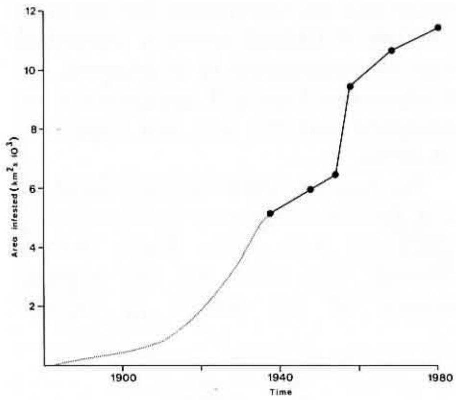


Figure 5 Time course of spread of *Opuntia aurantiaca* in eastern New South Wales. Broken line: putative spread between 1883 and 1938.

Herbarium collections have been used as a measure of plant spread in England (Lacey, 1957) and the U.S.A. (Forcella and Harvey, 1982 and unpub. data). Herbarium records of these species are of limited use. There are only nine specimens of tiger pear collected between 1908 and 1981 (cf. Figure 1) in the National Herbarium, Sydney. For parthenium, cumulative records (a total of 42) from Queensland Herbarium and the Queensland Department of Lands Herbarium indicate rapid spread after 1975, agreeing with Figure 3 but later suggest a decreasing rate of spread (Figure 6), contrasting dramatically with the increase in spread found in the Department of Lands survey in the period (Figure 3).

Pattern of spread The frequency distribution of new infestations in relation to distance from previous infestations summarizes spread pattern (Figure 7 and Figure 8). Distributions of this kind can be described by the family of exponential curves.

$$n = ke^{-sf(d)} \quad \ldots (2)$$

n is the number of new infestations
e the exponential constant
$f(d)$ some function of distance, d,
and k and s are constants.

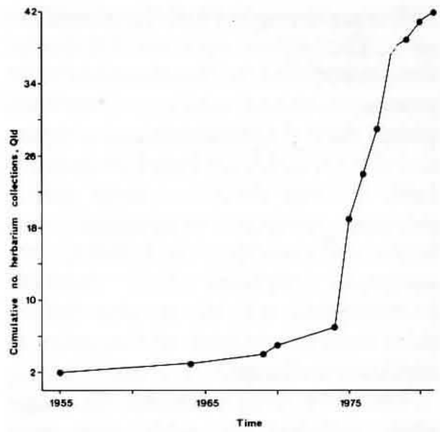


Figure 6 Cumulative number of herbarium records of *Parthenium hysterophorus* in Queensland.

Although Jones and Bartholomew (1971) used the area under such curves, the form commonly used by plant pathologists to describe disease gradients, a 'double log' model (Gregory, 1968) provides a convenient method of comparing curves, where

$$\log n = c - s \log d \quad \ldots (3)$$
c is a constant

n can be transformed to $n + 1$ to accommodate zero readings. However this introduces an artefact (Gregory, 1968). In fitting these curves to our data we have cut off the series when two consecutive zeros are reached.

The regression coefficient, s, which we shall call the 'spread gradient' is a single parameter which is a useful first approximation of spread pattern. The greater the magnitude of s (see van der Plank, 1960) the greater is the tendency of the species to spread as an advancing front rather than as scattered isolated infestations. This is an important distinction because species which are able to establish isolated colonists, other things being equal, will ultimately tend to spread more rapidly than species which do not (see above) and will be more difficult to contain (Menz, Coote and Auld, 1980).

That all of the spread population arose from one point source can be a legitimate assumption only over an interval of one reproductive cycle. Thus all the data shown here include secondary spread, which tends to flatten the gradients; an effect which increases with time. However, when taken over the same or similar time intervals the data can be usefully compared. Values for s and their standard errors in brackets are shown on Figure 7 and Figure 8.

Although useful as a first approximation, the s values derived from a fit of log/log by least squares analysis, provide only a crude description of spread pattern. The rare isolated infestations at great distance must be considered separately in this kind of analysis. Over the 20-year period which the tiger pear gradients represent, these outlying infestations may have arisen in a series of short 'jumps' (Figure 7). However, the data for parthenium 1979–81 (Figure 8) represent a gradient with only two years possible secondary spread; the number of new infestations more than 50 km from previous infestations is alarming.

The spread gradients for tiger pear are increasing (Figure 7) and thus its potential spread rate is reduced. The time intervals for spread of parthenium (Figure 8) vary, so that a comparison of *s* values is difficult. We would expect the value of *s* for the shorter period (1979–81) to be greater than for the 1975–79 period because of less opportunity for secondary spread. However the gradients are not significantly ($P > 0.05$) different and increased future spread rate for parthenium is indicated.

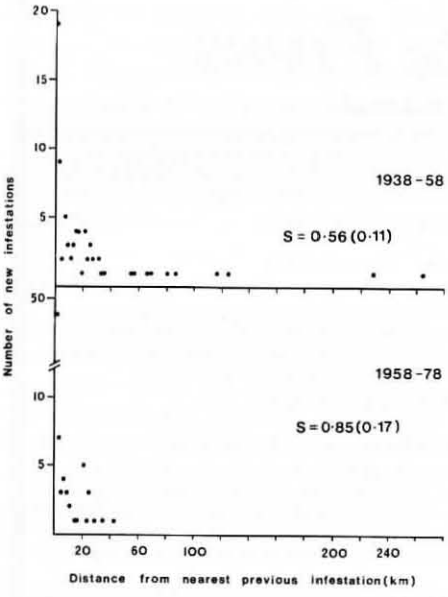


Figure 7 Spread gradients of *Opuntia aurantiaca* in New South Wales; *s* values (see eqn. 3) and standard errors are indicated.

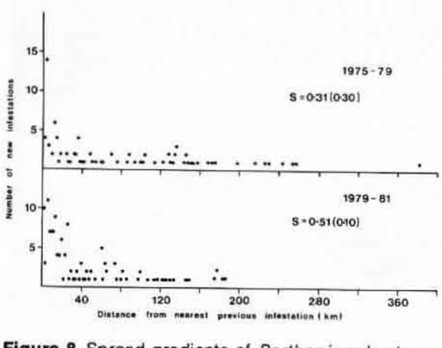


Figure 8 Spread gradients of *Parthenium hysterophorus* in Queensland; *s* values (see eqn. 3) and standard errors are indicated.

General discussion

Tiger pear's rate of spread has decreased recently since more trained staff with better vehicles and 'prickly pear spray'* have been used. However, the total area of infested properties is vast and the species still poses great logistical problems simply in locating plants. Control is made more difficult on the steep terrain where it is frequently necessary. The possibility of the species' ecological limitation adjacent to rivers has not been investigated. In South Africa, it has spread over areas between rivers.

The spread of tiger pear in South Africa has followed a sigmoidal form (Figure 9). The rate of spread there appears to have decreased with a more intensive inspection system and regular treatment (Moran and Annecke, 1979).

Because of the large propagule size a strongly 'advancing front' type spread could reasonably be anticipated. However, the river system has provided a mechanism for long distance transport. Several new infestations occurred at considerable distances from previous infestations (Figure 1). Although the possibility of further flooding exists in New South Wales, it is unlikely ever to be as serious and widespread as the 1955 event because of subsequent extensive flood mitigation works. Apart from river transport, the most likely sources of new infestations would be through stock transport and garden escapes.

Parthenium weed's spread rate in Queensland has continued to increase (Figure 2). The spread gradients for the species are shallow (Figure 8) and it is capable of being transported long distances. There appears to be a vast area to the south of its present distribution which is susceptible to invasion (Doley, 1977; Williams and Groves, 1980). In the Collinsville area, however, the apparent effects of a control programme are seen in a reduced spread rate, where the area susceptible to infestation remains large (Figure 4).

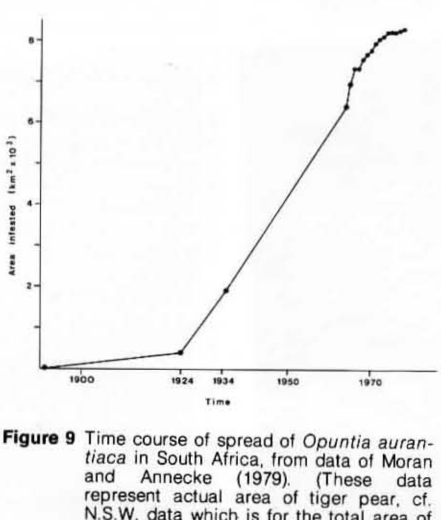


Figure 9 Time course of spread of *Opuntia aurantiaca* in South Africa, from data of Moran and Annecke (1979). (These data represent actual area of tiger pear, cf. N.S.W. data which is for the total area of properties infested with tiger pear. The authors indicate data from 1964 may be underestimated by 7% because of the exclusion of certain areas.)

Simulation may provide a means of estimating future spread rates and evaluating control policies. Auld and Coote (1981) and Auld, Vere and Coote (in press) have demonstrated this for serrated tussock, *Nassella trichotoma*, in a limited area. However, some assessment of the potential range of the species is required for larger scale simulation. Such studies (e.g. Medd and Smith, 1978) are, of themselves, useful in planning control policies. It is, however, difficult to predict edaphic limitations to species which are intolerant of shading, such as parthenium (Williams and Groves, 1980), or require light to germinate, where ground cover can fluctuate markedly within their potential climatic range.

Conclusion

Tiger pear established new infestations at considerable distances from previous infestations during 1938–58 which enhanced its potential spread rate. Yet its spread rate decreased suggesting some success in the containment measures referred to above. Although the spread rate of parthenium weed appears to have been decreased in a limited area by a control programme, containment appears to be difficult. A strong public awareness campaign to help locate rare isolated new infestations is imperative if the species is to be contained to any extent.

Acknowledgements

We thank the organizers of the International Symposium on the Biological Control of Weeds, Brisbane, 1980, which was where this paper was conceived, and Miss Julie Morris who prepared the figures. We are also grateful to Dr P. Harris and Dr D. A. Friend for comments on the manuscript.

References

Auld, B. A. and Coote, B. G. (1980). A model of a spreading plant population. *Oikos* **34**:287–92.

Auld, B. A. and Coote, B. G. (1981). Prediction of pasture invasion by *Nassella trichotoma* (Gramineae) in south east Australia. *Protection Ecology* **3**:271–7.

*2,4,5-T (15.7 g L^{-1}): picloram (0.62 g L^{-1})

Auld, B. A., Menz, K. M. and Monaghan, N. M. (1979). Dynamics of weed spread: implications for policies of public control. *Protection Ecology* **1**:141–8.

Auld, B. A., Vere, D. T. and Coote, B. G. (in press). Evaluation of control policies for the grassland weed, *Nassella trichotoma*, in south-east Australia. *Protection Ecology*.

Doley, D. (1977). Parthenium weed (*Parthenium hysterophorus* L.): gas exchange characteristics as a basis for prediction of its geographic distribution. *Australian Journal of Agricultural Research* **28**:449–60.

Forcella, F. and Harvey, S. J. (1982). Spread of *Filago arvensis* L. (Compositae) in the United States. *Madrono* **29**:119–21.

Gregory, P. H. (1968). Interpreting plant disease dispersal gradients. *Annual Review of Phytopathology* **6**:189–212.

Jeffers, J. N. R. (1978). *An Introduction to Systems Analysis: with ecological applications*. Edward Arnold, London. 198 pp.

Jones, R. I. and Bartholomew, P. E. (1971). A way to measure the spread of plants from a focus. *Proceedings of the Grassland Society of Southern Africa* **6**:170–5.

Lacey, W. S. (1957). A comparison of the spread of *Galinsoga parviflora* and *G. ciliata* in Britain. In *Progress in the Study of British Flora* Lousley, J. E. (Ed). B.S.B.I. Conf. Rep. 5, Abroath. pp. 109–15.

Mack, R. N. (1981). Invasion of *Bromus tectorum* L. into western North America: an ecological chronical. *Agro-Ecosystems* **7**:145–65.

Madden, L. V. (1980). Quantification of disease progression. *Protection Ecology* **2**:159–76.

Maiden, J. H. (1911a). The prickly pears of interest to Australians. No. 1. *Agricultural Gazette of New South Wales* **22**:321–8.

Maiden, J. H. (1911b). Spread of *Opuntia aurantiaca* (prickly pear). *Agricultural Gazette of New South Wales* **22**:1048.

Medd, R. W. and Smith, R. G. C. (1978). Prediction of the potential distribution of *Carduus nutans* (nodding thistle) in Australia. *Journal of Applied Ecology* **15**:603–12.

Menz, K. M. and Auld, B. A. (1977). Galvanised burr, control, and public policy towards weeds. *Search* **8**:281–7.

Menz, K. M., Coote, B. G. and Auld, B. A. (1980). Spatial aspects of weed control. *Agricultural Systems* **6**:67–75.

Moran, V. C. and Annecke, D. P. (1979). Critical reviews of biological pest control in South Africa. 3. The jointed cactus, *Opuntia aurantiaca* Lindley. *Journal of the Entomological Society of South Africa* **42**:299–329.

Rüdenauer, von B., Rüdenauer, K. and Seybold, S. (1974). Uber die Ausbreitung von *Helianthus* und *Solidago* — Arten in Wurttemberg. *Gessellschaft fur Naturkunde in Wurttemberg. Jahreshefte* **129**:65–77.

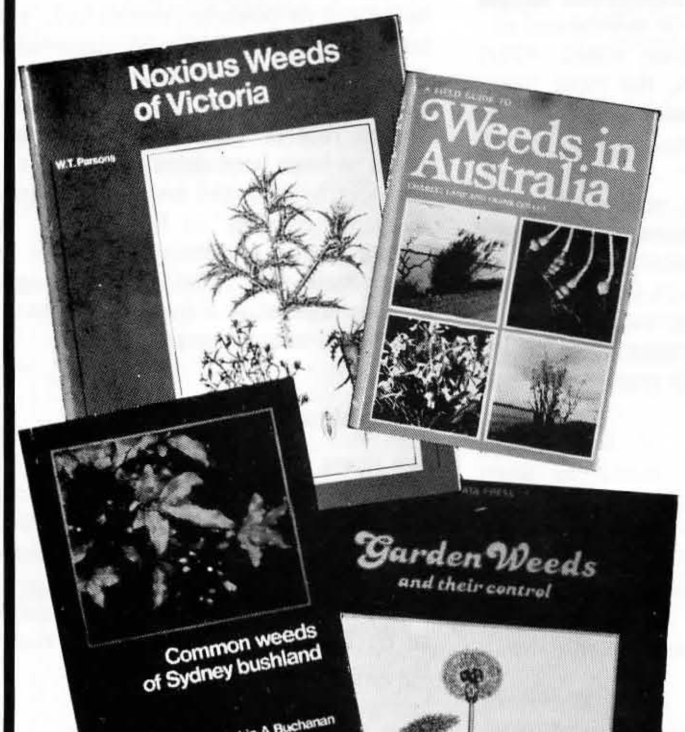
van der Plank, J. E. (1960). Analysis of epidemics. In *Plant Pathology*. Horsfall, J. G. and Dimond, A. E. (Eds) Vol 3, chapter 7. Academic Press, New York, pp. 229–89.

Water Resources Commission (1980). *Flood Information Reports. Floods in the Namoi Valley*. Water Resources Commission, New South Wales, Gov. Printer, Sydney. 46 pp.

Watson, K. A. (1979). Control of *Parthenium hysterophorus* with picloram and 2,4-D in central Queensland. *Proceedings Seventh Asian-Pacific Weed Science Society Conference, Sydney*. pp. 133–6.

Williams, J. D. and Groves, R. H. (1980). The influence of temperature and photoperiod on growth and development of *Parthenium hysterophorus* L. *Weed Research* **20**:47–52.

Weed books from Inkata Press



A Field Guide to Weeds in Australia C. Lamp and F. Collet
This excellent manual is invaluable to all who are interested in identifying the members of this familiar group of plants. Weeds are arranged in alphabetical order of botanical names, with at least one illustration for each, and an index of common names for easy access.
376 pages 1976 Hardback A$19.95 plus P/P $2.50

Noxious Weeds of Victoria W. T. Parsons
Detailed descriptions of the declared noxious weeds, many colour and half-tone illustrations, and comprehensive information on the control of each weed are included. Introductory discussion on the principles of weed control, herbicides and the equipment for their application makes this a book of great value throughout the Australasian region.
300 pages 1973 Hardback A$24.95 plus P/P $2.50

Garden Weeds and Their Control R. J. Chancellor and Hilary Broad
An essential book for every gardener, this scholarly yet practical work has a key to weed identification, a discussion of seven methods of weed control and their application in various parts of the garden, instructions on how to use herbicides, and a table of weeds and their susceptibilities. Exquisite illustrations by Hilary Broad enhance the descriptions.
93 pages 1980 Hardback A$15.95 plus P/P $2.50

Common Weeds of Sydney Bushland Robin Buchanan
Many areas of natural bushland which have been preserved or simply left behind amidst Sydney's urban growth are threatened by the encroachment of weeds. This attractive book is an essential companion to all who enjoy Sydney's bushland and seek to combat the threat of weeds to this valuable recreational area.
136 pages 1981 Limp A$9.95 plus P/P $1.00

ORDER FORM

Inkata Press Pty Ltd
4 Longbourne Avenue
North Clayton 3168 Vic Australia Tel.: 03 560 0272

Please supply copy/copies of ____________

Name ____________

Address ____________

____________ *I enclose cheque for $* ______