WEED SPREAD AND GOVERNMENT INTERVENTION

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Summary. A brief analysis of government intervention in weed control is presented. The importance of externalities as the basis for noxious plant declarations is discussed. Since external costs are a result of weeds spreading this aspect of applied plant ecology is seen as one requiring further attention. An outline of spread pattern description and simulation of spread is presented.

WHY ARE GOVERNMENTS INVOLVED IN WEED CONTROL?

Governments are involved with weeds in a variety of ways: in research, in extension, and in implementation of noxious-plant legislation. In general terms, intervention takes place when society desires, and decides to enforce, a level of control different from that achieved by private owners/managers. This seems to have occurred for three reasons: (a) ignorance of the private and social benefits of control, and of available methods in the private sector; (b) economies of large scale which are unavailable to private land managers; and (c) externalities (18).

Ignorance. The effects of weed control especially in pastures depend upon a complex interaction between the control method used and other factors such as associated vegetation, stocking rate and climate (3). It is difficult to translate the physical consequence of control into a measure of economic benefit, since weed control is only part of the overall production process. Since there will always be uncertainty regarding the benefits and costs of weed control, there will be misinvestment (under or over) in it which can be attributed to ignorance.

However, steps can be taken to provide farmers with, at any rate, the best available information. Once this is done, relative ignorance will no longer be a source of discrepancies between socially and individually desired levels of control.

Extending the best available information to farmers may be one sound investment; another may be research on weed spread and private and public control strategies: current public control strategies are formulated "without full knowledge of the actual ... losses to be prevented and the relevant economic factors involved" (9).

Cost economies. Economies of size are more likely in research into control methods where specialised skills and equipment are required. This would of course be true for private firms as well as for government. However, the problem for private industry is that of capturing economic benefits from their research efforts: only when research on weed control is likely to result in a marketable patented product is it attractive to private industry.

While not falling directly into the classification of an economy of size, a related reason for government intervention would be to coordinate control measures. This is obviously important in the case of classical biological control, but would appear to be an area worthy of attention even with more conventional control measures.

Externalities. Externalities are costs or benefits outside the domain of the individual decision-maker: consequences for others which he would not take into account in his own interests. In relation to weed control, externalities will occur when farmer A controls weeds on his farm and benefits are provided thereby to neighbouring farmer B in the form of reduced risk of infestation; alternatively, if farmer A fails to control weeds, then B's risk of infestation increases.

Expressed mathematically the profit functions of the two farmers take the form:

$$T_A = p.F_A\ (W_A.W_B) - C_A.W_A$$

$$T_B = p.F_B\ (W_A.W_B) - C_B.W_B$$

where T is profit, p price received for products, F quantity of output expressed as a function of weed quantity W, and C is the unit cost of weed control and (after 22).

It is unlikely that those in receipt of external benefits will voluntarily compensate the provider, or that those who have costs thus imposed upon them will receive compensation. The private level of weed control will therefore be less than the socially desired level.

Prior to 1908, liability for weed control on private property in N.S.W., for instance, was governed by the maxim *Sic utere tuo ut alienum non laedus*, which, freely translated, means "you must use your own land (or goods) in such a way as not to injure another". The case of Sparke *v*, Osborne (1908) 7 C.L.R.51, decided by the High Court of Australia, laid down that an occupier of land has no duty at common law to control a noxious weed growing naturally on his land so as to prevent it from spreading or extending to his neighbour's land; and that if, owing to his failure to keep it down, it grows in such a way as to damage his neighbour's fence, that is not sufficient to render him liable. The maxim quoted above was held by Mr. Justice Isaacs to render a person liable for damage due to weeds only if the damage was *encouraged* by the intervention of his human act. Mr. Isaacs specifically held that normal farming operations do not constitute such intervention. Since the common law thus assigned no liability to an owner of weed-infested land, this liability was assigned by statute (21).

This government intervention via noxious-plant legislation is thus a direct response to the problem of externalities since noxiousness is proclaimed if "the plant is likely to spread... (and) worthwhile benefit to the community is reasonably anticipated" (26).

In summary, governments are involved with weeds (a) via research, (b) in educating farmers by extension activities, and (c) via legislation - the major form of intervention - in response to externalities which are due to the risk of the weed spreading across landholders' boundaries.

As soon as weed spread across farm boundaries occurs the private optimal level of weed control falls below the socially desirable level. Moreover, the faster the rate of spread, the greater the divergence between private and public optimal levels of control (28). Therefore, other things being equal, the faster the rate of spread of a weed, the stronger is the rationale for public intervention and assistance in the weed control process. Since external costs arise as a result of *spreading*, the study of this aspect of weed ecology is a prerequisite to the formulation of sensible public control strategies (7).

WEED SPREAD

Given the importance of the spread of weeds in formulating public policies of control, it is surprising that there has been so little study of this aspect of weed ecology.

Previous descriptions of spread. Increasing rates of spread of invasive plant species are quite common (6, 15, 24). Lacey (14) used log plots to describe the spread of two *Galinsoga* species in England. However, these data were based on total records and not records in new areas, hence population growth rates and spreads (i.e. invasion into new territory) rates were confounded. Moreover, unless the area into which a species spreads 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 (16). The predictive value of this kind of approach to modelling weed spread is limited by the need for some estimate of final area infested as well as the requirement for a number of observations during the early years of spread. In cases where there is a sudden, short lived, increase in spread, for example as occurred in the spread of tiger pear, *Opuntia aurantiaca*, in N.S.W. as the result of floods in 1955 (6), no single simple function can describe spread, but catastrophe theory (e.g. see (13)) could possibly provide the basis for the description of such changes.

Factors affecting spread rate. The spread of plant species can be described by four principal parameters (1):

(a) Population growth rate at a primary infection site of finite area.

(b) The proportion of the annual increase in population which is dispersed beyond the boundaries of the primary site.

(c) The area over which (b) is dispersed.

(d) The susceptibility of invaded areas to colonization.

The greater the population growth rate of a species the greater will be its rate of spread, other things being equal.

For species which spread solely by wind-borne seeds the proportion of the annual increase in population which is dispersed is usually very small. However, for weed species which are dispersed by other means, particularly with the intrusion of man and in farm produce, as, for example, contaminants of cereal grains and straw, the dispersing fraction may be very high. For instance, Thurston (1964; cited by Sagar and Mortimer, 25) recorded an 81% dispersing fraction for wild oats, *Avena fatua*. Thomas et al. (27) made a study of the movements of grain and hay in drought periods during 1980-81 to one area of south-eastern Australia. They found that several weed species which were "restricted" or "prohibited" for quarantine purposes occurred with a high frequency in samples they examined. For example, wild oats seeds occurred in 65% of grain samples and 32% of hay samples; sheep sorrel, *Rumex acetosella*, occurred in 15% of grain samples and 29% of hay samples. The hay came from as far as 1000 km away; the amount varied with distance and the severity of the drought.

The distribution in space of the dispersing fraction of the annual increase in population produces a "pattern of spread". Species which are dispersed in farm produce or by man, as in the case of wild oats cited, would generally have a much less predictable pattern of spread than species spread by "natural" agents such as wind. In the latter case the number of propagules decreases very markedly as a function of distance from the source (12), although wind borne grass inflorescences and "tumbleweeds" (e.g. *Sclerolaena muricata*) do travel considerable distances, especially in rangeland areas.

The importance of susceptibility of invaded areas to colonization in the population dynamics and spread of species has been demonstrated for a number of pasture weeds (e.g. variegated thistle, *Silybum marianum* (20) serrated tussock, *Nassella trichotoma* (8) and crofton weed, *Ageratina* (*Eupatorium*) *adenophora* (2)). In each case the invading species has been kept in check by competition and occupation of available space by pasture species.

Interaction between rate and pattern. Species which have a scattered pattern of spread will, other things being equal, spread at a faster rate than species which spread as an advancing annulus, or front (4).

Thus not only are the dispersal distance of propagules and the size of the parent population important in determining spread rate but also the distribution of that population in space. Species which establish at a number of isolated nuclei will tend to spread (i.e. occupy new areas) at a faster rate than a species being dispersed from one location. Therefore, pattern of spread can indicate relative future rates of spread.

Spread Pattern Description. The frequency distribution of new infestations in relation to distance from previous infestations summarizes spread pattern. Distributions of this kind can be described by the family of exponential curves:

$$n = ke^{-sf(d)}$$

where n is the number of new infestations, e the exponential constant $f(d)$ some function of distance, d, and k and s are constants. The form commonly used by plant pathologists to describe disease gradients, a "double log" model (11) provides a convenient method of comparing curves, where

$$\log n = c - s \log d$$

where c is a constant and n can be transformed to $n + 1$ to accommodate zero readings. However, this introduces an artefact (11); in fitting these curves the series can be cut off when, for instance, 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 23) the greater is the tendency of the species to spread as an advancing annulus or front rather than as scattered isolated infestations. Conversely, low values of s indicate a scatter of infestations which, other things being equal, would have a combined spread rate greater than that from an advancing front of the same sized population. {See (6) for a discussion of examples}.

The assumption that all of the spread population arose from one point source can only be legitimate over an interval of one reproductive cycle. Data over longer periods include secondary spread, which tends to produce flatter gradients; an effect which increases with time.

Simulation. Another approach to prediction of future spread of a weed species is by simulation.

Auld and Coote (1) described a model of plant spread based on the four parameters described (above).

(a) Population growth rate (*c*) at an infection site. This was assumed to be a constant exponential rate until a "saturation" population, which remains constant, is reached.

(b) The proportion (*s*) of the annual population increase which is dispersed beyond the boundaries of the infection site. It was argued that this could be assumed constant.

These two parameters can be combined in the equation:

$$P_n = P_i \left(1 + \frac{c}{100}\right)^n \left(1 - \frac{s}{100}\right)^n$$

where P_n is the population in year *n* and 100 represents a saturation population.

(c) The area over which the fraction (*s*) is dispersed.

(d) The susceptibility of invaded areas to colonization.

These four parameters were estimated for the perennial grass serrated tussock which spreads by wind-borne panicles of seeds, from observations made by weed inspectors and scientists and the further spread of the species was predicted within an area in which it already occurred (1). This model was then used to assess control strategies for the weed (5).

In addition the model was earlier used in a more general way to examine spatial aspects of weed control strategies (19).

In current research B.G. Coote and I are refining our spread model to simulate smaller scale spread of species deliberately introduced into new areas. The model is also being used for annual species which means that saturation populations cannot be regarded as permanent or infinitely recurring.

Potential distribution. With some knowledge of the factors which affect a species distribution, an attempt can be made to define the potential distribution of invading species. This is more readily accomplished where there are specific temperature or day length responses for germination and flowering; not common in weeds. This kind of assessment has been made for nodding thistle, *Carduus nutans* ssp. *nutans* (17), and in a more general way for parthenium weed, *Parthenium hysterophorus*, (10, 29). Medd and Smith (17) developed a model to predict growth, phenological development and seed yield of nodding thistle at 286 climatic stations throughout Australia. Predicted seed yields were used to rank stations into four categories of potential distribution.

CONCLUSION

Since external costs arise only as a result of spreading, study of this aspect of weed ecology is a prerequisite to the formulation of sensible public and private control strategies. Indeed, such studies are necessary to determine whether there is any need at all for public policies in relation to weeds. Research on the spread of weeds should be given a high priority, in the light of the total public resources devoted to implementing present noxious-plants legislation.

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