AN ANALYSIS OF SPREAD OF SKELETON WEED, *CHONDRILLA JUNCEA* L., IN WESTERN AUSTRALIA

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Summary. Since it was first recorded on a farm in W.A. in 1963, skeleton weed, *Chondrilla juncea*, has been found on 210 farms, scattered mostly throughout the northern and central wheatbelt. The total area infested is less than 1000 ha, however, and eradication has been achieved on 25% of the farms. The number of infested properties found each year has risen from an average of one per year over the first 10 years, to 22 per year since 1981/82, and the cumulative total has risen exponentially. If current rates of finding infested farms are maintained, it is estimated that the cumulative total will increase to between 500 and 1,900 in 15 years, according to the choice of model for predicting spread.

INTRODUCTION

Skeleton weed was introduced to Australia early this century and has become one of the most economically significant weeds in cereal crops (8). It was first found in W.A. in 1963 (5), since when small but increasing numbers of infestations have been found virtually every year, mostly on farms, as well as along railway lines and (in Perth) in marshalling yards and freight terminals (9). Roadside infestations are rare. Infestations are generally small, varying in size from single plants to populations up to 100 ha in extent (8). The discovery of several infestations with a combined area of approximately 100 ha in Narembeen Shire during summer 1973/74 (2) led to the establishment in 1974 of the Skeleton Weed Eradication Fund, administered by the Agriculture Protection Board of W.A. (A.P.B.), to pay expenses related to the eradication and the prevention of spread of skeleton weed in W.A. Annual expenditure currently totals approximately $600,000 (3).

When skeleton weed is found, infested farms are quarantined immediately and eradication procedures are begun. Intensive searches are made of all infested and adjoining farms, with the help of large numbers of volunteers, mostly farmers. A farm is cleared from quarantine after the infested paddock has been cropped three times without further plants being found. Because of the close attention paid to skeleton weed, detailed records have been kept of the locations of known infestations. In recent years, there has been substantial increase in the number of infested farms found each year and an expansion in the geographic range of skeleton weed. There has also been increasing difficulty in obtaining enough volunteers to participate in the expanding search effort. In order to estimate the future possible extent of skeleton weed in W.A., records of infestations were analysed with the use of models of weed spread (1).

METHODS

Yearly totals of skeleton weed finds were obtained from published reports (9, 6) and A.P.B. files. A farm is recorded as infested even if it contains a single plant. The increase of known infestations was shown by plotting the cumulative total number of infested farms found since 1963/64. Their locations were mapped to show their distribution in the state. Exponential curves were fitted a) to the entire data set, and b) to the totals for 1973/74 onwards, when intensive searches were initiated as part of the eradication campaign. A linear regression was fitted to the totals since 1980/81. The

resulting functions were used to provide predictions of the cumulative number of finds up to the end of this century. An analysis was made of the sizes of individual infestations, using the available data on infested farms reported up to 1981/82.

Two of the three morphological forms of skeleton weed distinguished by Hull and Groves (4) are known to occur in W.A. (6): these are the narrow-leaved Form A, and the broad-leaved Form C. The form of skeleton weed was determined for 35% of infestations in W.A., by means of gel electrophoresis (6), examination of live inflorescence stems, herbarium specimens and, in a few cases, photographs. Because of the similarity of their inflorescence stems, it is possible that some populations typed as Form C were actually intermediate-leaved Form B: electrophoresis would need to be used where there was a doubt of this kind.

RESULTS AND DISCUSSION

Distribution of known infestations. To date, skeleton weed has been found on 201 farms in 26 shires of the south-west of the state (Table 1). Three distinct phases are apparent in the annual records of skeleton weed finds. In the 10 years after skeleton weed was first recorded, infestations were found on nine farms located in widely separated parts of the state at Geraldton (2 farms), near Ballidu (3), Badgingarra (1), and Esperance (3), suggesting that there had been a number of separate introductions of the weed. Over this period, the rate of detection averaged one farm a year. Between 1973/74 and 1980/81, following the discovery of nine infestations at Narembeen and the start of intensive annual searches, a further 63 farms were quarantined for skeleton weed, at an average rate of eight per year. Of this total, 37 (59%) were in the Narembeen district. From 1981/82 to present, a further 129 farms ($\bar{x}$ = 22/yr) were quarantined. Skeleton weed has been found on a total of 89 farms in Narembeen Shire, which represents 44% of the state total.

Table 1. Annual and cumulative totals for finds of skeleton weed on farms in Western Australia

Year	No. finds	Cumulative total	Year	No. finds	Cumulative total	Year	No. finds	Cumulative total
1963/4	1	1	1973/4	10	19	1981/2	24	96
1964/5	0	1	1974/5	7	26	1982/3	20	116
1965/6	2	3	1975/6	9	35	1983/4	24	140
1966/7	0	3	1976/7	4	39	1984/5	13	153
1967/8	0	3	1977/8	9	48	1985/6	16	169
1968/9	2	5	1978/9	9	57	1986/7	32	201
1969/70	1	6	1979/80	6	63			
1970/1	0	6	1980/1	9	72			
1971/2	1	7						
1972/3	2	9						
Mean	0.9			7.9			21.5	

Infestation size. Up to 1981/82, infestations on farms ranged from single plants to a maximum of 14 ha. Sixty three per cent were <1 ha in extent, 32% were <0.1 ha, while 18% consisted of one or a few plants on 1-4 m^2. Only 3% exceeded 10 ha.

Eradication of skeleton weed. The eradication campaign has resulted in the elimination of skeleton weed from 50 (25%) of the quarantined farms. Eradication has been achieved throughout the range of skeleton weed, although the eradication rate in the Narembeen Shire is only half that for the rest of the state: by mid 1987, skeleton weed had been eradicated at 16 of the 89 farms quarantined in Narembeen Shire, giving an eradication rate of 18% whereas comparable figures for the rest of the state were 37 farms released out of 112 or 33%.

Distribution of forms. Form A has been collected widely throughout the main distrution from Geraldton to Southern Cross. It has also been found near Perth and Albany. To date, only Form A has been collected from the northern areas of the wheatbelt (6). The distribution of Form C is centred strongly on Narembeen Shire. The 23 populations identified to form in this Shire have all been Form C. This form has also been recorded from the adjoining shires and near Esperance, Albany and in the Perth area. The southern part of the main range of Form A overlaps with the northern part of the distribution of Form C, in the central wheatbelt between Goomalling and Yilgarn Shires (6). There is no reason why Form C should not be successful in the northern wheatbelt, throughout the range of Form A. The co-occurrence of both forms on one farm has been recorded only once, in Yilgarn Shire.

Predicting the increase of skeleton weed. Increasing rates of spread of invasive plant species are quite common (1), especially during the early stages of invasion when exponential spread rates can be obtained. Ultimately, though, the rates of spread will slow down, such as when the area available reaches saturation or in response to control measures (1). The exponential increase in the number of infestations found since 1963/64 suggests that the total amount of skeleton weed in the state is also increasing exponentially and that a proportion of the total is being detected. Although the exponential model of spread is inappropriate unless the area into which the plant is spreading is infinite (1), the area of the W.A. wheatbelt available for invasion is very large compared to that already occupied and is, effectively, infinite. It would, therefore, seem appropriate to use the exponential model, both to describe the pattern of increase to date, and to generate short-term forecasts. As an alternative, the linear model assumes that there will be no further increase in the numbers of new infestations found each year and that the annual rate of finds will remain around 20% (Table 1).

Estimates of the number of infested farms to be expected in 5, 10, and 15 years time, according to the exponential and linear models, are given in Table 2. The exponential models forecast a 7 or 9 fold increase after 15 years, leading to cumulative totals of 1,500 or 1,900 infested properties by 2001/2. The comparable total forecast by the linear model is 500.

If the rate of skeleton weed finds continues to increase exponentially, there would be an enormous increase in workload for the A.P.B.'s skeleton weed eradication branch, especially if the present eradication strategy is maintained. Even the conservative forecast (i.e. from the linear model) indicates as considerable increase in the A.P.B.'s commitment.

Table 2. Forecasts of the cumulative totals of infested farms. Year 0 = 1986/87, when the cumulative total = 201

Model	Start of data	Cumulative total of infested farms 5 years (1991/2)	10 years (1996/7)	15 years (2001/2)
Exponential	1963/4	434	910	1,893
Exponential	1973/4	401	776	1,481
Linear	1980/1	297	398	500

Potential distribution of skeleton weed in Western Australia. Evaluation of the climatic characteristics of locations throughout the range of skeleton weed in south-eastern and south-western Australia has shown that virtually the entire W.A. wheatbelt is climatically suitable for infestations (7). At present, infestations are scattered throughout the northern and central parts of the wheatbelt, but are not known to occur in the southern wheatbelt. It has been recommended (7) that priority be given to preventing invasion of the latter area. The ocurrence of infestations near the south coast at Esperance (now eradicated) and Albany, confirm the vulnerability of the southern region.

The history of skeleton weed in south-eastern Australia is one of rapid spread, leading to almost complete occupation of the cereal-growing areas of N.S.W., Victoria and S.A. Skeleton weed can produce large numbers of wind-dispersed seeds (3) which are the plant's primary means of dispersal. Their rate of spread is increased through the movement of stock and by means of road and rail transport (8). The amount of rail and road traffic entering W.A. has risen substantially since the completion of the Standard Gauge Railway Line and the sealing of the Eyre Highway (in 1968 and 1976, respectively) and, despite the existing interstate quarantine measures, skeleton weed seeds will continue to enter the state by road and rail, providing the source for new infestations.

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