# SIZE-BIOMASS RELATIONSHIPS FOR AUSTRALIAN POPULATIONS OF THE INVASIVE RANGELAND SHRUB *PARKINSONIA ACULEATA* L.

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*Abstract*

*Parkinsonia aculeata* is an invasive, introduced shrub that is found in all mainland states of Australia except Victoria. It is especially prevalent north of the tropic of Capricorn. Size-biomass relationships were established for this species using data from 167 shrubs spread across eight sites in the Northern Territory and north-eastern Queensland. Above-ground dry weight (W, kg) can be predicted from plant height (H, m), canopy diameter (D, m) or stem cross-sectional area (A, $cm^2$) using the equations:

$$W = 0.025\ H^{4.47}$$

$$W = 0.091\ D^{3.64}$$

$$W = 0.022\ A^{1.61}$$

These relationships are linear when plotted on log-log scales. Although there was a significant effect of "site" on the log-log relationships between above-ground dry weight and size variables, the amount of information lost by not using site-specific equations is relatively small. These results provide reliable methods for estimating above-ground biomass in this species, the most robust being based on measurements of stem diameter at 20 cm above ground level.

*Key words*: *Parkinsonia*, weeds

## Introduction

*Parkinsonia aculeata* L. (parkinsonia, Jerusalem thorn) is a shrub that is native to tropical South America but that was deliberately introduced to Australia as a shade and ornamental species. It is now an important weed of Australian rangelands. It is of concern to extensive grazing industries and a significant environmental weed, particularly given its prevalence in wetter parts of the landscapes that it invades (ARMCANZ, ANZECC 2001). It is a declared plant in Queensland, the Northern Territory, Western Australia, South Australia and New South Wales (Parsons and Cuthbertson 1992), and a Weed Of National Significance (WONS) (Thorp and Lynch 2000). It occupies over 800,000 ha of Western Australia, the Northern Territory and Queensland with scattered infestations in South Australia and New South Wales (Thorp and Lynch 2000). In spite of this importance there have been few studies of the ecology of the species in Australia. Much effort has focused on identifying and releasing potential biological control agents (e.g. Woods 1986, Flanagan *et al.* 1996, Lukitsch and Wilson 1999, Donnelly 2000).

The study described here was conducted as a prelude to a more detailed investigation of the population biology of *P. aculeata* at representative sites across its Australian range. We analysed the relationships between above-ground biomass of individual plants and various measures of plant size. This was needed because, as yet, it is not possible to determine the age of individuals of this species, and because it is likely that above-ground biomass is a superior descriptor of pattern and change in some important population parameters. The aim was to provide simple, reliable predictors of above-ground biomass that could be used as a basis for documenting population structure and recording growth and demographic responses of this important rangeland weed. The approach sought predictors that could be applied to populations that spanned a wide variety of plant densities, population structures and landscape positions. The relationships between the various measures of plant size were also explored.

Size-biomass relationships have been determined for many woody plant species. Such relationships have been used to estimate timber production in commercially important tree species (e.g. Ter-Mikaelian and Korzukhin 1997), to estimate production of browse for wildlife (e.g. Hughes *et al.* 1987) and as a basis for describing the structure and function of forest, woodland or shrubland communities (e.g. Ludwig *et al.* 1975). In Australian rangelands, size-biomass relationships have been examined for a number of native species including *Eucalyptus incrassata* Labill. (Holland 1969), some common trees and shrubs of semi-arid woodlands (Harrington 1979) and the arid zone shrub *Acacia victoriae* Benth. (Grice *et al.* 1994).

Some work has been done on size-biomass relationships of invasive species. For example, Van *et al.* (2000) established a regression relationship between above-ground dry weight and trunk diameter at breast height for invasive populations of the native Australian tree *Melaleuca quinquinervia* (Cav.) S.T.Blake growing in Florida. In Australia, Grice (1996) related above-ground biomass of the invasive tropical shrubs *Cryptostegia grandiflora* Roxb. ex R.Br. and *Ziziphus mauritiana* Lam. to plant height.

## Methods

Six study sites (sites 1-6) were selected on cattle properties in north-eastern Queensland and two (sites 7 and 8) in the Northern Territory. Together they covered a range of landscape positions and densities of stands of *P. aculeata*. Sites 1-4 were south of Charters Towers in the catchment of the Cape River. Sites 5 and 6 were between Prairie and Hughenden in the upper reaches of the catchment of the Flinders River. Sites 7 and 8 were located in the catchments of the Victoria and Roper Rivers respectively (Table 1, Fig. 1).

**Table 1.** Locations and landscape descriptions of eight study sites in Queensland and the Northern Territory. Estimates of the density of *Parkinsonia aculeata* are from Grice *et al.* (in prep.).

| Site no. | Property name | Latitude | Longitude | Landscape position | Plant density (per ha) |
|---|---|---|---|---|---|
| 1 | Taemus | 21°0'S | 146°21'E | Riparian | 4826 |
| 2 | Taemus | 21°0'S | 146°22'E | Upland | 33 |
| 3 | Caerphilly | 21°2'S | 146°33'E | Riparian | 567 |
| 4 | Caerphilly | 21°2'S | 146°32'E | Upland | 338 |
| 5 | Mona Vale | 20°52'S | 144°27'E | Riparian | 39 |
| 6 | Ellington | 20°53'S | 144°27'E | Upland | 782 |
| 7 | Auvergne | 15°23'S | 130°16'E | Riparian | 40 |
| 8 | Elsey | 14°55'S | 133°22'E | Riparian | 50 |

At each site, approximately 20 plants were selected to represent the size range present at the site. Plants were generally unevenly spread across sites, so effort was made to select individuals from across the range of plant densities that existed at each site (Table 1). Each of the plants was measured, harvested, weighed, dried, and then reweighed.

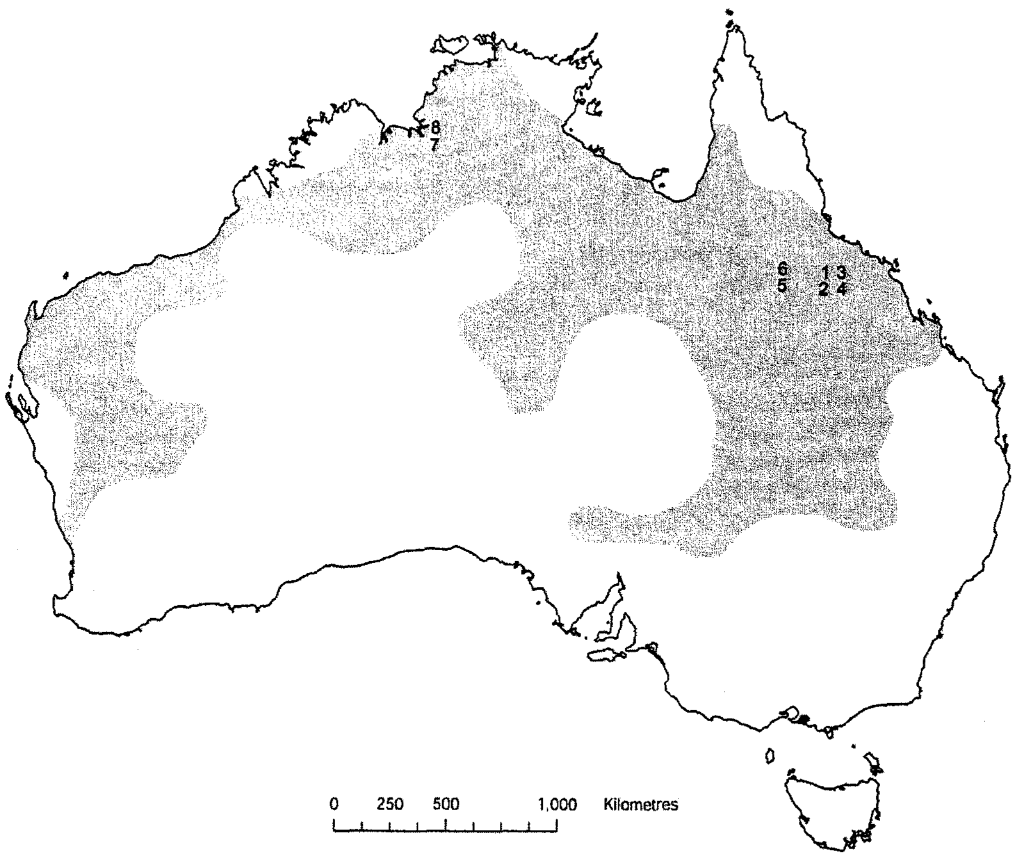



**Fig. 1.** Distribution of *Parkinsonia aculeata* in Australia (after Thorp and Lynch 2000) and locations of eight study sites (numbered according to Table 1).

Prior to harvesting, the following measurements were taken from each plant:

(i) height (H) – measured with an accuracy of ± 0.05 m;
(ii) canopy diameter ($D_1$, $D_2$) – measured in two orthogonal directions (north-south, east-west) with an accuracy of ± 0.05 m;
(iii) stem diameter ($d_1$, $d_2$, $d_3$ etc) measured at a height of 20 cm above ground level, along a north-south axis using calipers and recorded with an accuracy of ± 0.5 mm; each stem of multi-stemmed plants was measured;
(iv) biomass index (I) assigned using the method of Andrew *et al.* (1979, 1981) at sites 1-6 only; this involved selecting an arbitrary standard unit and then assigning a value to each plant on the basis of the number of standard units it was estimated to contain. The same observer (ACG) was used at each site.

Each stem was cut off at ground level using a chain saw, and the whole plant weighed using a spring balance with a capacity of 15 kg ± 0.025 kg. In cases where individual plants weighed more than 15 kg, the material was sub-divided into portions of 15 kg or less and each portion weighed separately. The plant was then either cut up by hand or shredded using a commercial mulching machine. The mulching machine was operated from a trailer, the sides of which ensured that very little material (<<1%) was lost during the shredding process. The resultant material was then bagged, dried to constant weight and reweighed. Field work was undertaken during the dry season (July – October 2001) though plants still retained foliage at this time.

To examine the relationships between size parameters and above-ground biomass, the following measures of size were used:

(i) height (H, m) – as measured in the field;
(ii) canopy diameter (D, m) – calculated as:

$$D = (D_1 + D_2)/2;$$

(iii) total stem cross sectional area (A, $cm^2$) – determined by assuming stems were circular in cross-section and calculated as:

$$A = \pi[(d_1/2)^2 + (d_2/2)^2 + (d_3/2)^2 + \ldots]$$

(iv) biomass index (I).

Initially, best-fit relationships between above-ground dry weight and each measure of plant size were considered using the curve-fitting function in Curve Expert 1.34 (Hyams 1995). Consistent with the results of studies of size-biomass relationships in other species, power functions most frequently fitted the untransformed data for *P. aculeata*. Subsequently, log-log transformed data were used as a basis for inter-site comparisons, using the simple linear regression with groups function within Genstat 5. Genstat and CurveExpert yielded identical equations describing the log-log relationships between above-ground biomass and size variables. However, these are not exact algebraic derivations of the corresponding power functions from CurveExpert. This is because the log-log relationships are derived by a least squares method whereas CurveExpert uses an iterative procedure to fit non-linear relationships.

Best-fit relationships between pairs of size variables were derived using CurveExpert 1.34.

**Results**

Sampled plants spanned a broad range of the variables measured (Table 2). Above-ground wet weight ranged from 0.002 kg to over 230 kg while above-ground dry weights ranged from 0.001 kg to over 140 kg. The ratio of wet weight to dry weight averaged 1.94 ± 0.60 (mean ± s.d.) (average % moisture 45.8%).

**Table 2.** Ranges of height, mean canopy diameter, stem cross-sectional area, above-ground wet weight and above-ground dry weight recorded at each site and for the combined sites.

| Site | Height (m) | Diameter (m) | Stem cross-sectional area ($cm^2$) | Wet weight (kg) | Dry weight (kg) |
|---|---|---|---|---|---|
| 1 | 0.75-4.85 | 0.25-6.15 | 0.1-148.4 | 0.02-72.5 | 0.01-40.0 |
| 2 | 0.80-4.80 | 0.25-6.25 | 0.2-104.8 | 0.02-91.2 | 0.01-51.5 |
| 3* | 0.50-6.60 | 0.25-7.02 | 0.2-285.6 | 0.01-237.4 | 0.01-144.2 |
| 4 | 0.45-4.20 | 0.20-4.55 | 0.03-52.8 | 0.05-38.3 | 0.01-20.9 |
| 5 | 0.50-4.80 | 0.15-5.15 | 0.1-105.7 | 0.01-57.8 | 0.01-30.0 |
| 6 | 1.20-4.80 | 0.35-5.60 | 0.4-103.8 | 0.04-71.8 | 0.02-37.0 |
| 7 | 3.00-6.45 | 1.80-6.90 | 11.5-196.6 | 4.50-163.0 | 2.30-118.0 |
| 8 | 0.70-6.00 | 0.05-5.45 | 0.05-121.0 | 0.01-65.9 | 0.01-40.1 |
| All | 0.45-6.60* | 0.05-7.02* | 0.03-285.6* | 0.01-237.4* | 0.01-144.2* |

* The largest plant measured and harvested at this site was excluded from the analysis of the combined sites data

The relationship between above-ground dry weight and plant height is such that for plants up to 2 m high, above-ground dry weight is less than 0.5 kg. Thereafter, above-ground dry weight increases relatively rapidly with plant height (Fig. 2). For individual sites, fitted power functions ($W = aH^b$) accounted for between 64% and 98% of the variation in above-ground dry weight, the equivalent value for the combined data being 74% (Table 3).

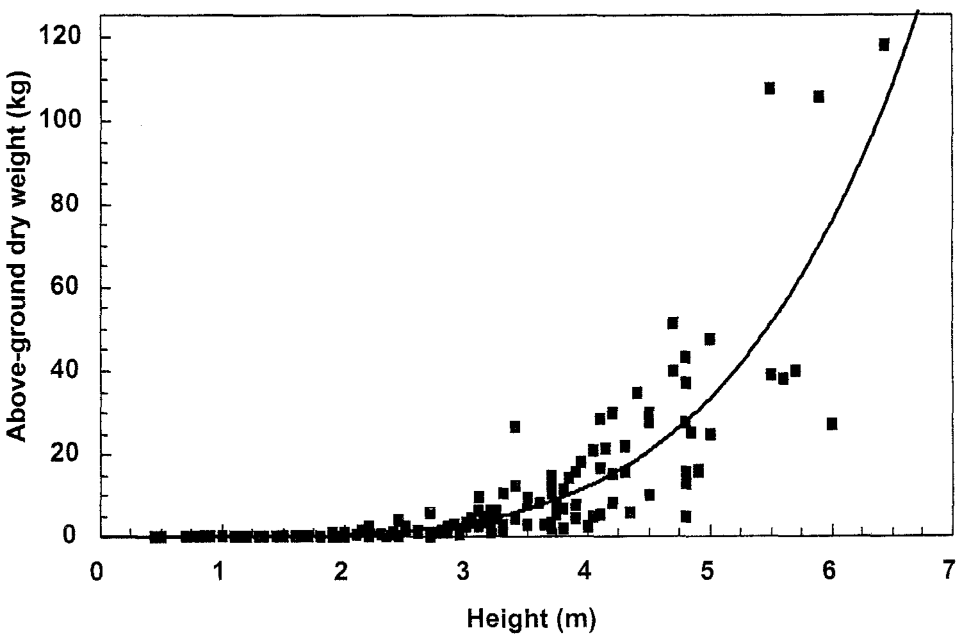



**Fig. 2.** Relationship between above-ground dry weight (W, kg) and plant height (H, m) based on combined data from eight sites

The relationship between above-ground dry weight and canopy diameter is such that plants with a mean canopy diameter of less than 2 m typically have an above-ground dry weight of less than 0.5 kg. For plants of diameters over 2 m, above-ground dry weight increases rapidly with increasing canopy diameter (Fig. 3). For individual sites, fitted power functions ($W = aD^b$) accounted for between 77 and 99% of the variation in above-ground dry weight, the equivalent value for the combined data being 86% (Table 3).

Plants with a total stem cross-sectional area of less than 50 $cm^2$ generally had an above-ground biomass of less than 20 kg, and in all plants with stem areas up to 150 $cm^2$, above-ground biomass was less than 60 kg. However, each of the plants with stem areas over 150 $cm^2$ weighed over 100 kg (Fig. 4). For individual sites, fitted power functions relating above-ground biomass to total stem cross-sectional area ($W = aA^b$) accounted for between 94% and 99% of the variation in above-ground dry weight and 92% for the combined data set (Table 3; Fig. 4).

The visual estimation technique yielded a relationship in which the biomass index was positively correlated with above-ground biomass (Fig. 5). The power functions ($W = aI^b$) for individual sites accounted for between 95 and 99% of the variation in above-ground biomass (Table 3), the corresponding value for the combined data being considerably lower at 87%.

For each measure of plant size, linear regression of log-log data for the combined sites yielded significant relationships ($P<0.001$) between size and above-ground dry weight (Table 4). For

**Table 3.** Power relationships between size measures and above-ground dry weight (kg) for each of eight sites and for the sites combined. a and b are the co-efficient and exponent respectively of a power function of the form $W = ax^b$ where x represents height (m), canopy diameter (m), stem-cross-sectional area ($cm^2$), or biomass index (no units). S.E., standard error; $R^2$, rounded to 2 decimal places.

| Site | a | b | S.E. | $R^2$ |
|---|---|---|---|---|
| Height (m) | | | | |
| 1 | 0.048 | 4.17 | 3.50 | 0.90 |
| 2 | 0.0083 | 5.51 | 3.92 | 0.93 |
| 3 | 0.00021 | 7.12 | 4.58 | 0.98 |
| 4 | 0.032 | 4.30 | 2.55 | 0.82 |
| 5 | 0.17 | 3.14 | 6.43 | 0.64 |
| 6 | 0.024 | 4.77 | 4.03 | 0.89 |
| 7 | 0.034 | 4.44 | 16.47 | 0.84 |
| 8 | 0.045 | 3.77 | 3.99 | 0.88 |
| All | 0.025 | 4.47 | 9.02 | 0.74 |
| Canopy diameter (m) | | | | |
| 1 | 0.21 | 2.90 | 1.47 | 0.98 |
| 2 | 0.15 | 3.15 | 1.87 | 0.98 |
| 3 | 0.11 | 3.28 | 0.35 | 0.995 |
| 4 | 0.14 | 3.21 | 2.88 | 0.77 |
| 5 | 0.12 | 3.35 | 3.23 | 0.91 |
| 6 | 0.44 | 2.62 | 2.24 | 0.97 |
| 7 | 0.49 | 2.87 | 9.31 | 0.95 |
| 8 | 0.28 | 2.95 | 2.61 | 0.95 |
| All | 0.091 | 3.64 | 6.67 | 0.86 |
| Stem cross-sectional area ($cm^2$) | | | | |
| 1 | 0.14 | 1.12 | 1.78 | 0.97 |
| 2 | 0.061 | 1.43 | 2.02 | 0.98 |
| 3 | 0.027 | 1.52 | 1.73 | 0.997 |
| 4 | 0.025 | 1.70 | 0.55 | 0.99 |
| 5 | 0.22 | 1.07 | 2.62 | 0.94 |
| 6 | 0.065 | 1.39 | 2.50 | 0.96 |
| 7 | 0.0064 | 1.86 | 10.02 | 0.94 |
| 8 | 0.18 | 1.13 | 2.22 | 0.96 |
| All | 0.022 | 1.61 | 5.08 | 0.92 |
| Biomass index | | | | |
| 1 | 0.0060 | 1.86 | 2.42 | 0.95 |
| 2 | 0.031 | 1.51 | 1.95 | 0.98 |
| 3 | 0.00034 | 2.64 | 1.52 | 0.998 |
| 4 | 0.044 | 1.26 | 0.94 | 0.98 |
| 5 | 0.011 | 1.73 | 1.90 | 0.97 |
| 6 | 0.0053 | 1.95 | 2.19 | 0.97 |
| All | 0.040 | 1.42 | 3.67 | 0.87 |

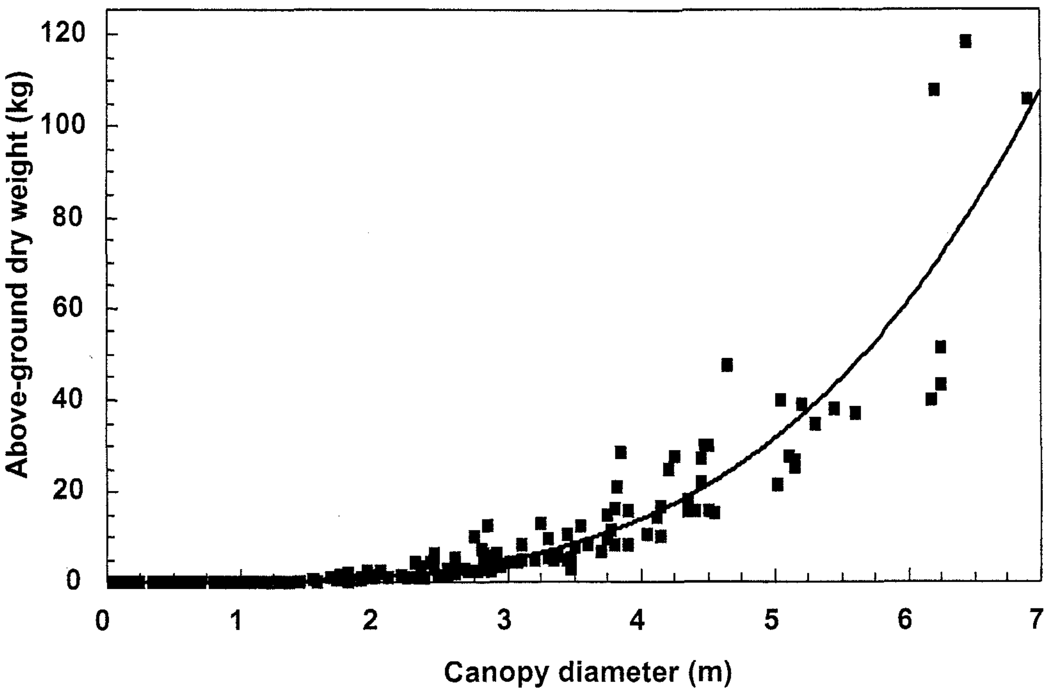



**Fig. 3.** Relationship between above-ground dry weight (W, kg) and canopy diameter (D, m) based on combined data from eight sites

each size variable, analysis of variance yielded significant effects of 'site' when data were classified into groups on the basis of site. However, in each case, including sites as a separate factor yielded only relatively small improvements in explanatory power (Table 4). The loss of explanatory power when 'site' effects are ignored varies between the different measures of plant size. The effect of 'site' was least for the relationship between above-ground dry weight and stem cross-sectional area than for the relationships between above-ground dry weight and the other size variables.

The three different measures of plant size are closely correlated with one another. Canopy diameter is linearly related to height (Fig. 6a). The ratio between canopy diameter and height is relatively low for small plants but is closer to 1:1 in larger plants. The best-fit relationships between stem cross-sectional area and both height (Fig. 6b) and canopy diameter (Fig. 6c) are power functions. Plants with height or canopy diameters up to about 2 m had stem cross-sectional areas of less than 10 $cm^2$. Stem cross-sectional area increased rapidly with increasing heights and/or canopy diameters greater than 2 m.

## Discussion

Non-destructive estimations of the above-ground biomass of woody plants require convenient, repeatable measures of plant size that show strong relationships with above-ground biomass that are, preferably, consistent across landscapes and between regions. Each of the measures of size of *P. aculeata* used in this study provides some basis for the non-destructive estimation of above-ground dry weight of this species but they vary in terms of convenience, repeatability and reliability.

**Table 4.** Results of analyses of variance on log-log transformed data showing the effects of plant size [height (H, m), canopy diameter (D, m), stem cross-sectional area (A, $cm^2$) and biomass index (I)] and 'Site' on above-ground biomass (W, kg). Regression equations of the form y = mx+k are shown for combined data from all sites.

| Model | Factor | m.s. | $R^2$ | F-probability |
|---|---|---|---|---|
| Constant + Log(H) | Log(H) | 205.0883 | 92.4 | <0.001 |
| Log(W) = 4.43[Log(H)] – 1.68 (n = 166) | Residual | 0.1021 | | |
| Constant + Log(H) + Site | Log(H) | 205.0883 | 94.0 | <0.001 |
| | Site | 0.6043 | | <0.001 |
| | Residual | 0.0799 | | |
| Constant + Log(H) + Site + Log(H).Site | Log(H) | 205.0883 | 94.1 | <0.001 |
| | Site | 0.6043 | | <0.001 |
| | Log(H)xSite | 0.1019 | | 0.258 |
| | Residual | 0.0788 | | |
| Constant + Log(D) | Log(D) | 206.2848 | 92.9 | <0.001 |
| Log(W) = 2.66[Log(D)] – 0.58 (n = 166) | Residual | 0.0949 | | |
| Constant + Log(D) + Site | Log(D) | 206.2848 | 94.9 | <0.001 |
| | Site | 0.6874 | | <0.001 |
| | Residual | 0.0686 | | |
| Constant + Log(D) + Site + Log(D).Site | Log(D) | 206.2848 | 96.0 | <0.001 |
| | Site | 0.6874 | | <0.001 |
| | Log(D)xSite | 0.3851 | | <0.001 |
| | Residual | 0.0539 | | |
| Constant + Log(A) | Log(A) | 217.0700 | 97.8 | <0.001 |
| Log(W) = 1.32[Log(A)] – 1.12 (n = 166) | Residual | 0.0296 | | |
| Constant + Log(A) + Site | Log(A) | 217.0700 | 97.9 | <0.001 |
| | Site | 0.0612 | | 0.040 |
| | Residual | 0.0282 | | |
| Constant + Log(A) + Site + Log(A).Site | Log(A) | 217.0700 | 98.0 | <0.001 |
| | Site | 0.0612 | | 0.034 |
| | Log(A)xSite | 0.0476 | | 0.103 |
| | Residual | 0.0273 | | |
| Constant + Log(I) | Log(I) | 128.7465 | 94.8 | <0.001 |
| Log(W) = 1.43[Log(I)] – 1.45 (n = 117) | Residual | 0.0602 | | |
| Constant + Log(I)+ Site | Log(I) | 128.7465 | 95.9 | <0.001 |
| | Site | 0.3292 | | <0.001 |
| | Residual | 0.0481 | | |
| Constant + Log(I) + Site + Log(I).Site | Log(I) | 128.7465 | 95.8 | <0.001 |
| | Site | 0.3292 | | <0.001 |
| | Log(A)xSite | 0.0431 | | 0.490 |
| | Residual | 0.0483 | | |

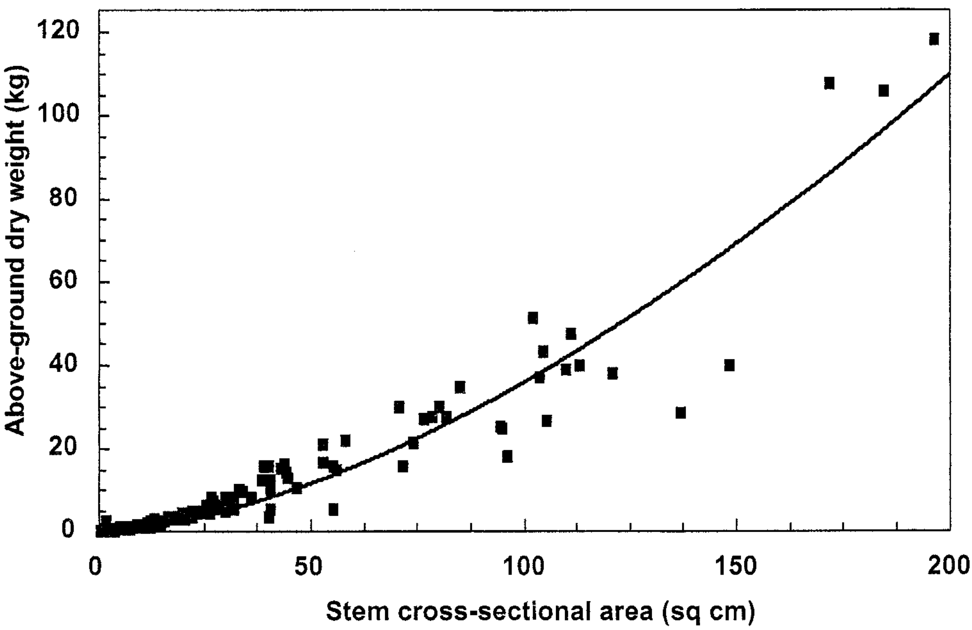



**Fig. 4.** Relationship between above-ground dry weight (W, kg) and stem cross-sectional area (A, $cm^2$) based on combined data from eight sites.

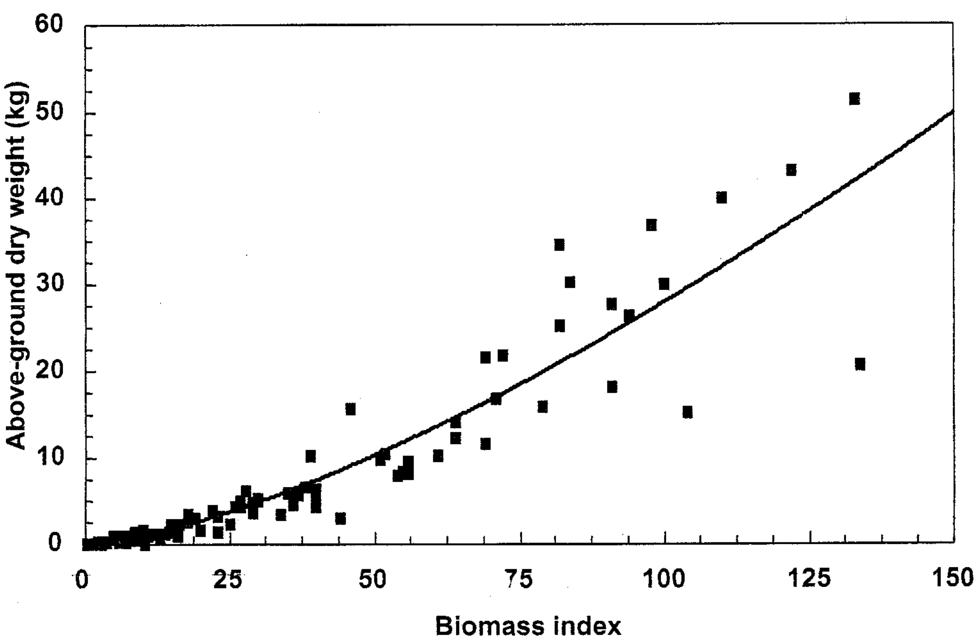
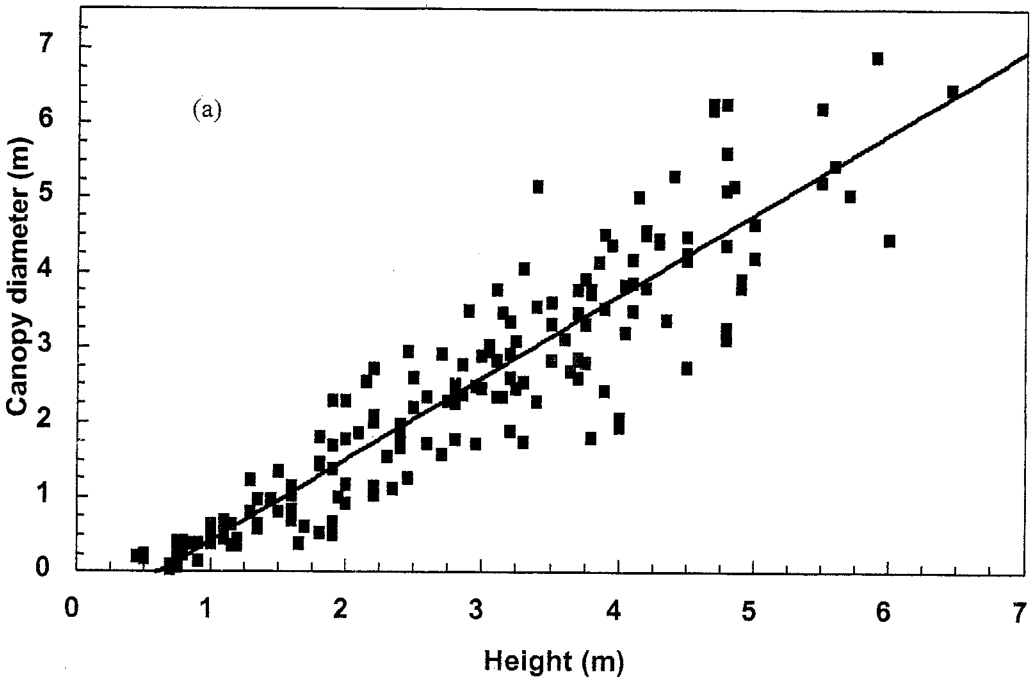
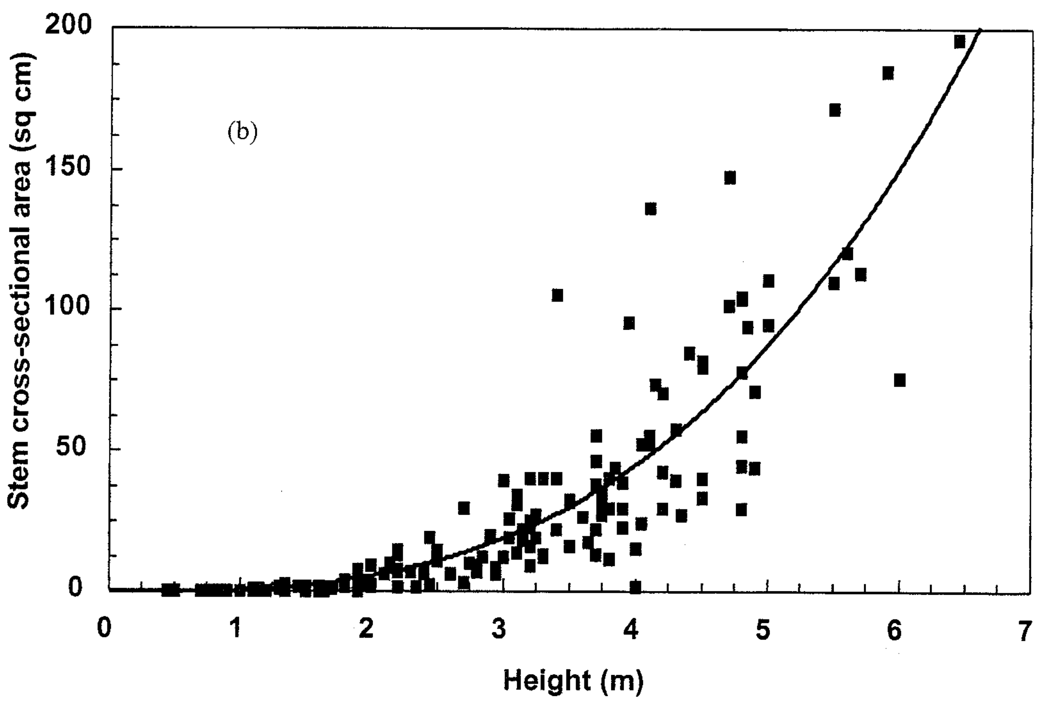
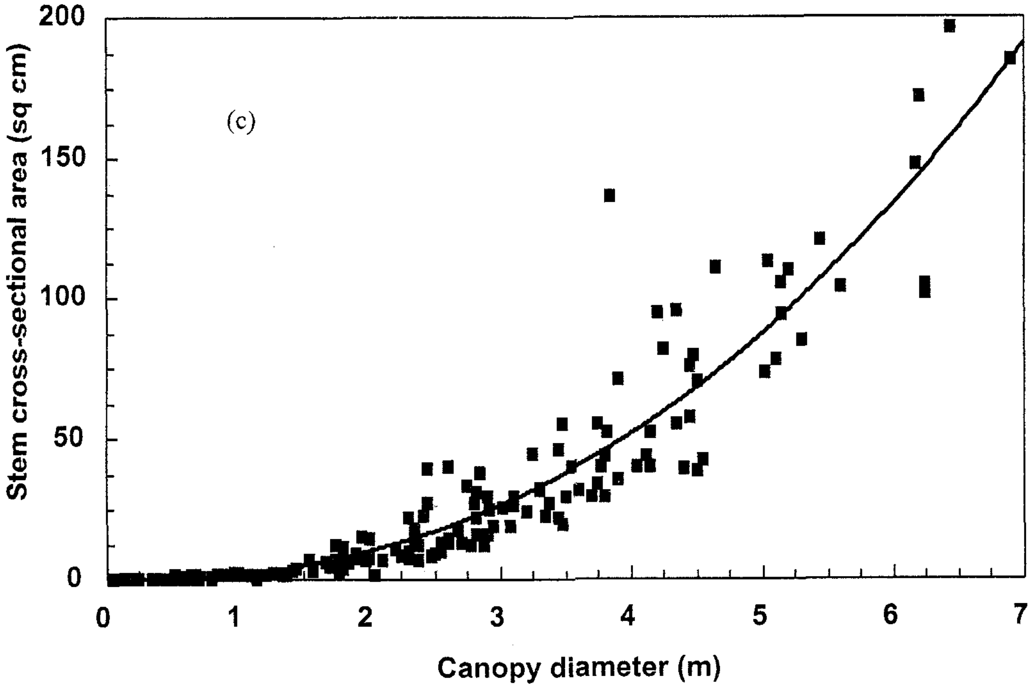



**Fig. 5.** Relationship between above-ground dry weight (W, kg) and visual biomass index (I) based on combined data from six sites

Plant height can be readily and reliably measured, but for some sites, the standard errors of predictions of above-ground dry weight are relatively high, ranging from 2.5 to 16.0 kg (Table 3).


(a)
Canopy diameter (m)
0
1
2
3
4
5
6
7
Height (m)
0
1
2
3
4
5
6
7


(b)
Stem cross-sectional area (sq cm)
0
50
100
150
200
Height (m)
0
1
2
3
4
5
6
7




←↑ **Fig. 6.** Relationships between three different measures of plant size. (a) Canopy diameter (D, m) versus plant height (H, m); [$D = 1.09H - 0.66$; S.E. = 0.65; $R^2 = 0.84$]; (b) stem cross-sectional area (A, $cm^2$) versus plant height (H, m); [$A = 0.74H^{2.97}$; S.E. = 18.65; $R^2 = 0.77$]; (c) stem cross-sectional area (A, $cm^2$) versus canopy diameter (D, m) [$A = 2.11D^{2.32}$; S.E. = 13.31; $R^2 = 0.88$].

There is also a close relationship between above-ground dry weight and canopy diameter. The standard errors of predictions for individual sites are somewhat lower than corresponding predictions based on plant height, but statistical comparison of log-log relationships indicate a relatively strong 'site' effect (Table 4). Inter-site variation in relationships between above-ground dry weight and height and canopy diameter probably results from the way the plants respond to density. The height : canopy diameter ratio is likely to be greater where plants are growing at higher density. It can be relatively time-consuming to measure canopy diameters, especially in dense stands.

Measuring stem diameter also provides a good basis for predicting above-ground biomass. The disadvantage of this measure of size is that multi-stemmed plants require multiple measurements that must be combined to give a single value. The approach used here was to assume that stems are circular in cross-section, calculate the cross-sectional area of each stem and sum them to give a single value for each plant. Standard errors of predictions for individual sites are relatively small (Table 3) and, for transformed data, using separate relationships for different sites gives only relatively small improvements in predictive capacity (Table 4).

The visual technique can be used as a basis for estimating above-ground biomass. However, different observers, or variation resulting when a single observer moved between sites, would contribute to inter-site variation. Such variability is not apparent in the data presented here, at least partly because only a single observer was used and the work was conducted over a relatively short period. The standards errors for best-fit relationships of untransformed data are relatively small and overall 'site' effects on log-log relationships are not significant. This technique for estimating above-ground biomass is more time-consuming than the techniques that require measuring one or even a few dimensions. Moreover, the visual technique would require the periodic harvesting of standards.

These results provide robust techniques for estimating above-ground dry weight of individuals of *P. aculeata*. Of the techniques considered, the most robust approach is that based on stem diameters measured at 20 cm above ground level. It is likely to be less prone than other techniques to inter-site variation and the effects of plant density. These techniques will be used to describe infestations of populations of *P. aculeata* and document change at the population level.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