A preliminary assessment of utilizable biomass in invading *Acacia* stands on the Cape coastal plains

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The biomass (woody material and foliage) of invasive Australian wattles (*Acacia cyclops, A. saligna* and *A. mearnsii*) was estimated in stands where crown cover exceeded 50% on the west coast, Agulhas and Eastern Cape coastal plains. Tree-level models were constructed to estimate biomass of the different plant components of *A. cyclops* and *A. saligna* from stem diameter at knee height. An existing volume regression equation for *A. mearnsii* was adapted and the estimated volumes, based on diameter at breast height, and tree height, were converted to mass. Sample plots were used to estimate mass per unit area by tree component, species and region. Satellite remote sensing conservatively estimated the densely (>50% cover) infested areas at >100 000 ha. The total green (wet) woody biomass with a minimum diameter of 2.5 cm was estimated to be almost 10 Mt or 12 million m^3. This is equivalent to the annual intake of roundwood by South African pulp, paper and board mills. A substantial quantity of raw material is therefore available for charcoal, wood composites and paper. Other products could possibly be developed from bark and foliage. Large-scale utilization of biomass will be a demanding task, with potential risks. Risks include environmental damage, and the creation of a dependency, and these will need to be managed carefully.

Introduction

This paper describes a preliminary assessment of the potentially exploitable biomass of invasive Australian wattle species in the lowland (coastal) areas of the Eastern and Western Cape provinces. We used extensive field sampling to develop models to estimate the biomass of single trees, and scaled these up using plot sampling and satellite remote sensing to arrive at estimates at a regional level. This study is the first attempt to estimate utilizable biomass for an invasive terrestrial species in South Africa.

The Working for Water programme is aimed at the sustainable control of invasive alien plants, but clearing dense infestations and site rehabilitation are expensive operations. Some of the alien plant species have utilizable wood, foliage, fruit and bark and making use of these by-products could offset costs. Furthermore, the harvesting, transport and value-adding operations could create additional employment.

To gauge the economic feasibility of using invader plants in a given area, an estimate of the potentially utilizable biomass was required. Our study focused on the coastal plains of the Western and Eastern Cape, and estimated the green biomass of three invasive Australian wattle species. We briefly describe the procedure and results of the inventory that was conducted to estimate the biomass, to enable interested companies to prepare well-founded bids for the conversion of the biomass.

Methods

In the first stage of the study, single-tree regression equations were constructed to estimate the exploitable biomass components of each species within each region. These 'tree level' models were then used to estimate the biomass of all trees on several plots of various sizes to obtain estimates of biomass per unit area. Finally, the size of the infested areas was estimated from satellite images and multiplied by the deduced biomass per unit area to obtain estimates of biomass at a regional level.

Tree-level models for estimating biomass

It is normal practice in forestry to estimate biomass, or volume as a substitute for biomass, by constructing tables or equations with easily measurable tree characteristics as predictor variables.[1] We stratified our sample of three invasive Australian *Acacia* species (rooikrans, *Acacia cyclops,* Port Jackson willow, *A. saligna,* and black wattle, *A. mearnsii*) with three regions (the west coast, Agulhas plains and Eastern Cape plains). Port Jackson willow was excluded from analysis of the Eastern Cape plains, and black wattle from the west coast (owing to their limited occurrence there). We assumed that trees with a diameter of less than 2.5 cm would not be utilized, and we differentiated further between woody biomass greater or less than 5 cm in diameter. We therefore constructed regression equations for Port Jackson and rooikrans trees with a diameter at knee height (DKH) between 2.5 and 5.0 cm and for those above 5.0 cm. The sample consisted of 656 trees (Table 1).

A quadratic equation was fitted with cross-sectional area at knee height and its square as predictors of mass, for each of the five region–species strata. These equations varied in their goodness of fit, and accounted for between 33.4% of the total variation explained for rooikrans in the Western Cape and 88% for Port Jackson willow in the Western Cape.

In the case of black wattle, estimation of biomass was based on a calculation of the volume of wood. Sampling sites were classified as being either dry, moist or wet, and at each of the sites the diameter at breast height (DBH) and the height of 30 trees were measured. These data were used to develop height–DBH regression equations (corrected to estimate under-bark volumes) for dry, moist and wet sites separately.

Stand-level inventories

Following the development of tree-level models, inventories were carried out to estimate biomass per unit area. Inventories were based on land units (farms or nature reserves), which varied in size and shape. Within each of the three regions, clusters of sample plots were established within identified land units, in proportion to the area of infestation within the land unit. The size of the sample plots varied according to stand density, such that each plot contained 15–25 trees (Table 2, Fig. 1).

The regression equations were used to estimate biomass on

Table 1. Number of trees sampled to construct single-tree regression equations to estimate biomass by region for two invasive *Acacia* species.

Region	Rooikrans (*Acacia cyclops*)	Port Jackson willow (*Acacia saligna*)	Total
Agulhas plains	103	100	203
Eastern Cape plains	101	–	101
West coast plains	92	260	352
Total	296	360	656

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Table 2. Number of sample plots of varying size used to estimate biomass per unit area of three invasive *Acacia* species in three regions.

Region	Species			Total
	Rooikrans (*Acacia cyclops*)	Port Jackson willow (*Acacia saligna*)	Black wattle (*Acacia mearnsii*)	
Agulhas plains	235	38	4	277
Eastern Cape plains	68	0	181	249
West coast plains	14	240	0	254
Total	317	278	185	780

each plot. To obtain control data for rooikrans, 10 sample plots of varying size and level of infestation were established on the Agulhas plains. The DKH and green woody biomass of the 2.5–5-cm diameter and the above 5-cm diameter categories were determined for each tree within each of these plots, and biomass was estimated using regressions. The trees were also felled and weighed separately, to establish the actual mass. Actual and estimated masses corresponded closely (Fig. 2).

The height of each black wattle tree on sample plots was estimated from DBH, using the appropriate equation for the site under consideration. Volumes were estimated in three parts. First, if DBH exceeded 7.5 cm, the under-bark volume to a thin-end diameter of 7.5 cm was determined from the standard volume regression equation for the species.[2] The height at which the tree was expected to have a thin-end diameter of 7.5 cm was estimated using the Demaerschalk equation, with the necessary coefficients.[2] Second, the height at which the tree was expected to have an under-bark diameter of 5.0 cm was calculated. The volume of the piece between the limits of 5.0 cm and 7.5 cm was determined by regarding the section as a truncated paraboloid. The process was repeated for the piece between 2.5 cm and 5.0 cm under-bark. The volume of the tree was determined as the sum of the three volumes so estimated. In the case of trees with DBH less than 7.5 cm, the volume of the section below breast height was calculated as a cylinder with diameter equal to DBH (under bark) and length of 1.3 m (that is, breast height) minus 0.15 m (the height at which the stump would be sawn). The heights at which the tree was expected to have under-bark diameters of 5.0 cm and 2.5 cm were then calculated, and volumes estimated as above. The volume of the tree was determined as the sum of the volumes of the three sections. Volume (m^3) was converted to wet mass (tonnes) by multiplying the former by 0.84 (ref. 2).

All biomass estimates were reduced by 10%, to allow for losses due to inefficiencies in harvesting practice.

Determination of infested areas with the aid of satellite images

Four recent, relatively cloud-free images were selected to observe the west coast plains, the Agulhas plains, and the Eastern Cape plains. Total infested areas and their densities were determined using seven spectral bands of the Enhanced Thematic Mapper sensor with a spatial resolution of 30 m. The evaluation and interpretation of the data sets was performed using ERDAS IMAGINE software (version 8.4). Owing to varying illumination conditions, the spectral reflectance properties of the terrain were affected in certain sections of the satellite images, possibly causing misclassifications. However, several of the areas that were identified on the satellite images as invaded by *Acacia* species were verified in the field with the aid of a global positioning system. This reduced possible bias in the estimation of the available biomass for each of the invading alien plant species and each of the regions. All areas with infestation levels of less than 50% crown cover were excluded from the calculations.

The analysis of the satellite images was based on a method developed to identify Port Jackson willow in a test area close to Atlantis in the Western Cape.[3] After geo-referencing, registering and normalizing the individual images, it was possible to perform a preliminary classification of the images. A model based on the ISODATA classification algorithm (that is, unsupervised classification) was designed for the identification of different levels of rooikrans, Port Jackson willow and black wattle infestations. Vegetation was selected with the Normalized Differenced Vegetation Index. This excluded all pixels not representing vegetation, for example bare soil, water and roads. The clustering process, employed to select vegetation in the image, was based on the natural groupings of similar pixels. This computer-automated procedure enables the user to specify the parameters chosen to uncover statistical patterns inherent in the data. Biomass estimation was carried out by calculating the number of pixels per class for all test areas and multiplied by the spatial resolution to obtain area (hectares) per class for each image. The total of all classes was used to reflect the overall infested area per image.

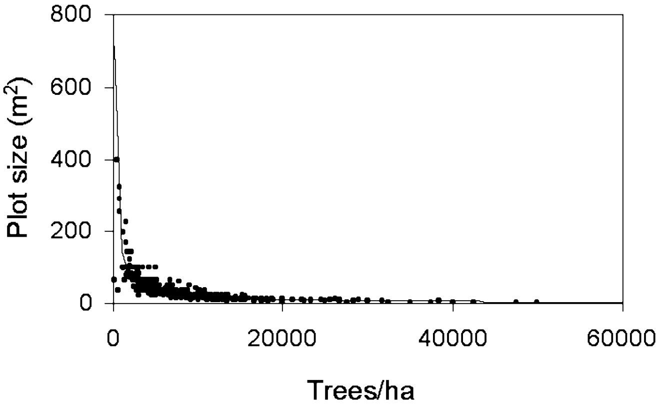

Fig. 1. Relationship between plot size used to estimate the biomass of invasive alien trees on 780 plots and the density of trees on each plot.

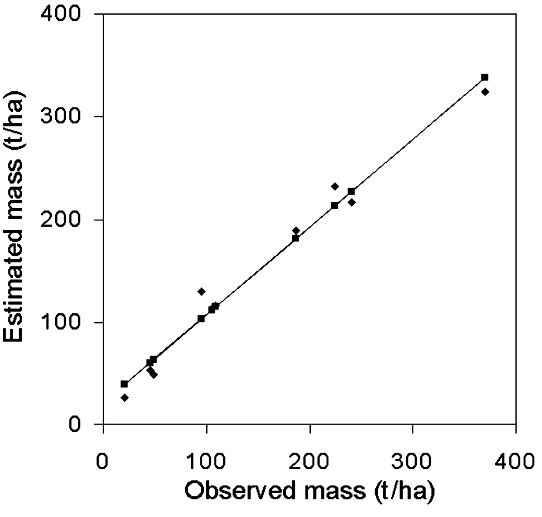

Fig. 2. Relationship between the biomass of rooikrans (*Acacia cyclops*) sampled on plots and estimates for the same plot using tree-level regression models.

Table 3. Areas (ha) with >50% crown cover infested by three invasive Australian *Acacia* species in three regions.

Species	West coast plains	Agulhas plains	Eastern Cape plains	Total
Rooikrans (*Acacia cyclops*)	2 840	11 794	28 179	42 813
Port Jackson willow (*Acacia saligna*)	8 417	3 492	48 537	1 909
Black wattle (*Acacia mearnsii*)	–	–	–	48 537
Total	11 257	15 286	76 716	103 259

Table 4. Estimated green biomass (tonnes) of woody material of different diameter classes, and foliage, for three species of invasive Australian wattles in three regions.

Biomass component	West coast plains	Agulhas plains	Eastern Cape plains	Total
Wood > 50 mm	169 450	764 869	5 757 356	6 691 675
Wood 25–50 mm	189 769	698 019	2 388 852	3 276 640
Branches < 25 mm	268 691	889 842	1 786 231	2 944 764
Foliage	191 856	499 546	1 225 295	1 916 697
Total biomass	819 766	2 852 276	11 157 734	14 829 776

Results

Over 100 000 ha within the study areas was estimated to be infested by the three species at a cover exceeding 50% (Table 3). Black wattle dominated in the Eastern Cape and rooikrans on the Agulhas plains. The estimated green biomass exceeded 14 Mt, of which the total woody biomass with a minimum diameter of > 2.5 cm was almost 10 Mt (Table 4).

Discussion

In Switzerland, equations similar to those used in our study have been successfully applied to measure and monitor the growth of forests of all ages.[4] The Swiss logarithmic model used log(DBH) as predictor and log(stem volume) up to a diameter of 12 or 24 cm as target variable. It was accepted that site quality affected the relationship between DBH and height. In consequence the estimates tended to be biased in individual stands. More recently, a stem diameter at a height of 6 m was introduced as second predictor variable, primarily to reduce site-associated bias.

Milton and Siegfried[5] determined that the green to dry biomass conversion factors of woody material are 0.68 for rooikrans and 0.61 for Port Jackson willow. The total of green woody biomass with a minimum diameter of 2.5 cm (Table 4) would therefore be approximately 6 Mt when dry. The standard forestry industry conversion factor of black wattle roundwood (t) to volume (m^3) is 1.19.[2] The volume of the almost 10 Mt green woody biomass with a minimum diameter of 2.5 cm is therefore almost 12 million m^3. To place this in perspective, the 1999/2000 intake by South African pulp, paper and board mills, and saw and veneer mills, was 12.442 million m^3 and 3.315 million m^3, respectively.[6] The woody biomass of invasive *Acacia* could be utilized for the production of charcoal, wood composites and paper. Other products could possibly be manufactured from bark and foliage.

Large-scale exploitation of biomass will impose several conditions. For example, the cooperation of many landowners will be required. Dense thickets, containing a high proportion of thin and crooked stems should be targeted. In sandy areas, the extraction of plant products may be a problem and not cost-effective if mass per unit area is low. Care will have to be taken not to spread seeds during harvesting operations. The activities related to harvesting of the biomass and adding value to it will inevitably have some adverse consequences for the environment, such as water and atmospheric pollution, and soil erosion and compaction. However, if the work is conducted with caution, the advantages of extra employment opportunities and reduced clearing costs as well as a decreased fire hazard should outweigh the disadvantages.

Rehabilitation after clearing provides a further challenge. Holmes and Richardson[7] developed a conceptual framework for efficient ecological restoration of fynbos. They emphasize the importance of conservation of the topsoil and recommend that in highly transformed sites, seed of selected species should be re-introduced soon after the alien plants have been removed.

The initiatives aimed at utilizing by-products of clearing should ideally be sustainable after the alien plants have been removed, and alternative sources may be required to fill the gaps once invasive species are no longer present. To avoid conflicts of interest between conservationists and harvesters, fast-growing, woody (preferably indigenous) species should replace the invader alien plants. Unfortunately, few such species are adapted to the coastal plains. Consequently, the establishment of woodlots scattered along the coastal belt may become a financially viable land-use option. Good management will be required to prevent the spread of the alien species from the woodlots. Biological control by means of selected seed-feeding insects should significantly reduce the invading potential of these species.[8]

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