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# Estimating Fuel Biomass of Some Shrub Species (Maquis) in Turkey

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**Abstract:** Regression equations were developed to estimate shrub fuel biomass of a maquis formation in western Turkey. The relationships between some shrub characteristics and live, dead, available (for consumption), and total fuel biomass were determined by simple/multiple linear regression. Measured biomass values for live, available, and total fuels varied from 0.70 to 6.74 kg $m^{-2}$, from 0.78 to 3.03 kg $m^{-2}$, and from 1.06 to 7.72 kg $m^{-2}$, respectively. The results obtained indicated that shrub fuel biomass could be satisfactorily predicted using the regression equations generated. The resulting equations were able to account for 60% to 89% of the observed variation ($P < 0.05$) in the fuel biomass categories studied. The results of this study should be invaluable in many forestry disciplines, including ecology, protection, and management.

Key Words: Fuel biomass, regression equations, shrubland, maquis, Turkey

## Türkiye'de Bazı Çalı Türleri (Maki) İçin Yanıcı Madde Kütlesi Tahmini

**Özet:** Türkiye'nin batı bölgelerindeki bazı maki türlerinde yanıcı madde miktarını tahmin etmek için regresyon eşitlikleri geliştirilmiştir. Bazı maki özellikleri ile toplam canlı, ölü, tüketilebilir ve toplam yanıcı madde biyokütlesi arasındaki ilişkiler basit/çoklu doğrusal regresyonlarla belirlenmiştir. Toplam canlı, toplam tüketilebilir ve genel toplam yanıcı madde biyokütlesi sırasıyla 0.70-6.74 kg $m^{-2}$, 0.78-3.03 kg $m^{-2}$ ve 1.06-7.72 kg $m^{-2}$ arasında değişmiştir. Sonuçlar, maki biyokütlesinin regresyon eşitlikleri ile doğru bir şekilde tahmin edilebileceğini göstermiştir. Toplam yanıcı madde biyokütlesindeki değişkenliğin % 60 ila 89'unu açıklayabilen eşitlikler geliştirilmiştir. Bu çalışmanın sonuçları, ekoloji, koruma ve amenajman gibi birçok ormancılık disiplini için değerli katkılar sağlayacaktır.

Anahtar Sözcükler: Yanıcı madde biyokütlesi, regresyon, çalı, maki, Türkiye

## Introduction

Estimates of biomass and fuel loads for various forest and range situations are important to land managers. Thus, biomass information needs and estimation methods have been frequently discussed in the literature of several forestry disciplines (Roussopoulos and Loomis, 1979; Mikaelian and Korzukhin, 1997; Sah et al., 2004). Biomass estimates are often used in determining the primary productivity of ecosystems, quantifying energy pathways, nutrient cycles, and product yields from harvest activities, evaluating wildlife habitats, and appraising forest fire potential.

The assessment of wildland fire behavior potential (Rothermel, 1972) requires quantitative estimates of available fuel weights by condition (living or dead) and by size category. The estimation of fuel biomass for large areas is also a prerequisite for successful fire management as it provides a more complete inventory for the area in question and quantifies combustible materials to help predict fire intensity and fire behavior (Gray and Reinhardt, 2003) in specific forest cover types and relates to the potential fire hazard reflected in different magnitudes over the stages of stand development (Lamberty et al., 2002).

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Many biomass studies have been conducted on shrub fuels (Brown, 1976; Ohmann et al., 1976; Grigal, 1977; Martin et al., 1981; Smith and Brand, 1983; Richard and Rugg, 1989; Buech and Rugg, 1995). The shrub complexes are known by various names such as fynbos (South Africa), mattoral (Chile), garrigue (France), chaparral (California, US) (Zhou et al., 2007), and maquis (Turkey). Shrub is one of the most important fuel types in the Mediterranean region and has long been associated with frequent forest fires. Therefore, numerous studies on fire prone communities have been carried out to establish the relationships between specific vegetation composition and/or structure (Papió and Trabaud, 1991; Pereira et al., 1995; Beaza et al., 1998) and fire behavior-vegetation height/flame height, horizontal and vertical fuel continuity/fire behavior, total biomass/fire intensity and severity (Fernandes, 2001; De Luis et al., 2004).

Fire prone shrubland plant communities and open oak and pine with a continuous shrub understory are widespread in Turkey and occupy about 6 million hectares (OGM, 2006), an area representing 27% of the country's forested lands. Thus, estimation of shrub fuel biomass is of crucial importance in fire, forest, and land management in the region (Bilgili and Saglam, 2003).

The principle objective of this study was to estimate fuel biomass of some shrub species in western Turkey for fire behavior prediction purposes. The results of this study will also prove useful in many forestry disciplines, such as ecology, protection, and management.

## Materials and Methods

### Description of the study area

The study was carried out in 2 localities: *i*) Söke State Forest, Aydın at 37°28´ N and 27°20´ E, and 80 m above sea level, and *ii*) Keşan State Forest, Edirne at 40°35´ N and 26°31´ E, and 30 m above sea level. Both localities represent the shrub fuel types most common in the western part of Turkey. The sites are mainly level to undulating with a mean slope ranging from 3% to 15%. Soils on both sites are shallow, and loam and sandy loam of limestone origin. Each area is characterized by typical Mediterranean climate with long hot summers and mild short winters. Mean annual rainfall is 1200 mm at the site in Söke and 650 mm in Keşan, with precipitation being mainly from November to May on both sites. The vegetation was an open shrubland with an average height of 0.53 m and 1.30 m in Söke and Keşan study areas, respectively. The dominant plant species was *Quercus coccifera* L., accompanied by *Arbutus andrachne* L., *Pistacia lentiscus* L., and *Sarcopoterium spinosum* L. at the site in Söke. The vegetation community studied in Keşan included maquis formations of the *Quercus-Phillyraea* alliance, and *Q. coccifera* was usually the dominant species.

### Sampling and measurement

Fuel biomass was determined based on 29 randomly selected sample plots (2 × 2 m). Measurements included vegetation height (H) and vegetation cover (VC). Height was measured as the vertical distance from the soil surface to the top of the branches. Measurements were obtained at 3 points along a transect running through the sampling plot, and then averaged to calculate the average height value for the plot. Shrub vegetation cover percent was measured on the sample plots by running 2 parallel transects on 2 sides of each plot. By adding the distances the transect ran over shrub crowns and figuring these as a fraction of total transect length, the percent shrub vegetation cover was calculated from (Martin et al., 1981):

Shrub vegetation cover percent = (Shrub cover length/total transect length) × 100

Shrub stems were cut at groundline, and each stem was divided into components of leaf and branches. The sampled shrub plots were cleared, and dead and live woody parts separated. All woody parts were further separated into size classes by diameter: 0 to 0.6 cm (fine fuels), 0.6 to 2.5 cm (medium branches), and 2.5 to 7.5 cm (thick branches) in diameters (Roussopoulos and Loomis, 1979; Martin et al., 1981; Brown, 1982). There was no plant material present larger than 7.5 cm in diameter. The size groups given here correspond to the 1-, 10-, and 100-h timelag fuels described in the literature (Deeming et al., 1972), and are important fuel biomass categories useful in calculating the intensity and severity of fires. Having completed the classification of fuel categories, all dead and live fuels were weighed on site using a 0.1 g sensitive electronic balance. Then subsamples of fuel biomass from each category were taken, weighed again, placed in nylon bags, labeled, and transferred to the laboratory for calculating oven-dry weights.

Apart from the fuel categories given, available (active) fuels composed of leaf plus fine branches less than 0.6 cm roundwood diameter were also analyzed as a separate category. Available fuels are considered readily available for consumption and, thus, very important for fire spread and fire intensity.

### Laboratory measurements

The fuel samples brought to the laboratory were oven-dried to a constant weight for 24 h at 100 ± 2 °C, and weighed to the nearest 0.01 g. Final fuel biomass determinations were made on the basis of oven-dry measurements.

### Statistical analysis

Correlation and regression analyses were performed to determine the relationship between biomass and shrub properties. Single nonlinear, single linear, and multiple regression equations for biomass estimation are commonly reported in the literature (Hitchcock and McDonnell, 1979; Smith and Brand, 1983). In this study, single and multiple linear regression procedures were used. Regression analyses considered physical properties as the independent variables and biomass categories as the dependent variables.

Prior to the analyses, the variables were tested for normality and as a result no transformation was deemed necessary for the variables. To analyze the relationships between biomass and independent variables, a stepwise function and linear regression models were used for predicting fine fuel, available fuel, and total fuel biomass. The relationship was of the form

$$(Y) = a + b(X_i) + \ldots + n(X_i) \qquad (1)$$

where Y is the dependent variable, $X_i$ are the independent variables, *a* is the constant, and *b* and *n* are the regression coefficients. All coefficients presented are for estimating biomass in kilograms in dry weight. All selected equations were significant at the 95% significance level. The evaluations of the goodness of fit and for use in comparing alternative biomass models the following statistics were calculated: the fit index or coefficient of determination, $R^2$ and the standard error (SE). Statistical analyses were performed using SPSS 10.0 for Windows (SPSS, Chicago, IL, USA).

## Results

The descriptive statistics of the shrub characteristics and fuel biomass are given in Table 1. Total height ranged from 30 cm to 230 cm while vegetation cover was between 40% and 98%. Oven-dry live fine fuel biomass ranged from 0.62 to 2.93 kg $m^{-2}$, live medium fuel biomass from 0.06 to 2.67 kg $m^{-2}$, and total live fuel biomass from 0.70 to 6.74 kg $m^{-2}$.

Available fuels are very important for fire spread and fire intensity. Total available fuel (live fine fuel + dead fine fuel) ranged from 0.78 to 3.03 kg $m^{-2}$. Total fuel biomass (live + dead fuels) ranged from 1.06 to 7.72 kg $m^{-2}$. Average total fuel biomass was 3.33 kg $m^{-2}$. In this study, total dead fuel biomass was very low in the diameter class, with an overall mean value of 13% of the total fuel biomass.

Correlation and regression analyses were undertaken to investigate the relationships between shrub properties

Table 1. Descriptive statistics for shrub fuel characteristics and fuel biomass.

| | | | Fuel biomass category (kg $m^{-2}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Live fuel | | | Dead fuel | | | Total fuel | | | |
| | | | Fine fuel | Medium fuel | Thick fuel | Fine fuel | Medium fuel | Thick fuel | | | | |
| | | | | Branch diameter (cm) | | | Branch diameter (cm) | | | | | |
| | H (cm) | VC (%) | (fol+branch < 0.6 cm in diameter) | 0.6-2.5 | 2.6-7.5 | (fol+branch < 0.6 cm in diameter) | 0.6-2.5 | 2.6-7.5 | Total live | Total dead | Total available | Total |
| Min | 30 | 40 | 0.62 | 0.06 | 0 | 0.03 | 0 | 0.02 | 0.70 | 0 | 0.78 | 1.06 |
| Max | 230 | 98 | 2.93 | 2.67 | 2.70 | 1.16 | 0.51 | 0.14 | 6.74 | 1.24 | 3.03 | 7.72 |
| Mean | 91.3 | 73.8 | 1.39 | 0.98 | 0.54 | 0.35 | 0.12 | 0.06 | 2.88 | 0.44 | 1.70 | 3.33 |
| SE | 11.6 | 3.2 | 0.11 | 0.12 | 0.14 | 0.05 | 0.02 | 0.01 | 0.34 | 0.06 | 0.12 | 0.36 |
| SD | 62.5 | 17.3 | 0.64 | 0.66 | 0.76 | 0.29 | 0.12 | 0.04 | 1.83 | 0.32 | 0.36 | 1.94 |
| N | 29 | 29 | 29 | 29 | 27 | 26 | 26 | 8 | 29 | 29 | 29 | 29 |

and associated shrub components' biomass. Correlation analysis results are given in Table 2.

The results from the present study showed that all biomass equations with height were highly significant for all components of shrubs (Table 2). Results of the correlation analysis indicated that total biomass was closely related to height and vegetation cover (r = 0.923, r = 0.754; $P < 0.01$), (Figure 1).

Furthermore, total biomass was well correlated with $H^2$ and H × VC (r = 0.907, r = 0.945; $P < 0.01$). The different linear biomass relationships of the different shrub parts as well as total biomass were separately compared and selected based on their $R^2$ values. As a result, the linear relationships between biomass and H, VC, $H^2$, and H × VC were chosen as the best fitted equations to the predicted live, available, and total fuel biomass (Table 3).

Height alone explained 87% of the observed variation ($P < 0.05$) in total live fuel biomass (Figure 2). Moreover, height alone explained 85% of the observed variation ($P < 0.05$) in total fuel biomass. Vegetation cover and height together explained 69% of the observed variation in total available fuel biomass. Furthermore, H × VC and $H^2$ together explained 74% of the observed variation ($P < 0.05$) in total available fuels (Figure 3). H × VC alone explained 89% of the observed variation ($P < 0.05$) in total fuel biomass (Figure 4).

## Discussion

The fuel load determines the potential amount of heat that can be released during a burn, whereas the type and distribution of fuel elements affect their combustibility. Fine fuels (diameter < 6 mm) burn more readily than coarse ones. The moisture contents of fuel affects the completeness of combustion (Bilgili and Saglam, 2003; Helly et al., 2003). Living tissues have higher moisture content than dead matter and therefore burn less readily (Gambiza et al., 2005). Fine fuels react faster to weather changes, particularly if these fuels are dead, and they play a major role in the initial stages of all fires (Baeza et al., 2002). In various chaparral species mixes (Countryman, 1964; Ottmar et al., 2000), it was reported that fine fuel loading ranged from 0.71 to 3.33 kg $m^{-2}$ (Weise et al., 2005).

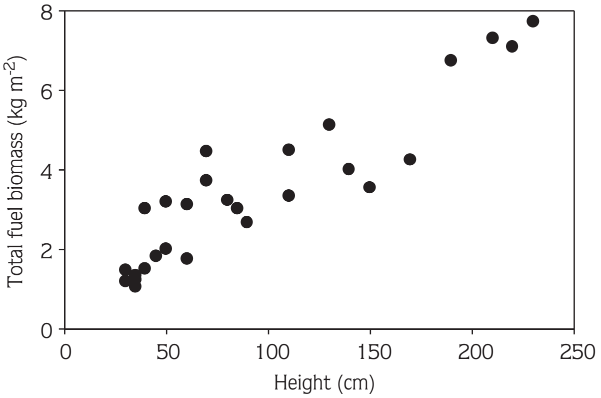

Figure 1. Correlation relationship between total biomass and height.

Available fuels are very important for fire spread and fire intensity. In this study, average total fuel biomass was 3.33 kg $m^{-2}$. Similar results were found in some Mediterranean shrublands (De Luis et al., 2004). Dimitrakopoulos (2002) reported total fuel biomass values of 3.6 kg $m^{-2}$ for Kermes oak shrublands. ICONA

Table 2. Correlation matrix of the variables used in the analyses (H: height (cm), VC: vegetation cover (%), H × VC: height (cm) multiple vegetation cover (%), $H^2$: height multiple height ($cm^2$), $F_{lf}$: live fine fuel (kg $m^{-2}$), $F_{ta}$: total available fuel (kg $m^{-2}$), T: total fuel biomass (kg $m^{-2}$).

| | H | VC | H × VC | $H^2$ | $F_{lf}$ | $F_{ta}$ | T |
|---|---|---|---|---|---|---|---|
| H | 1.000 | | | | | | |
| VC | 0.681** | 1.000 | | | | | |
| H × VC | 0.987** | 0.751** | 1.000 | | | | |
| $H^2$ | 0.977** | 0.604** | 0.973** | 1.000 | | | |
| $F_{lf}$ | 0.846** | 0.728** | 0.870** | 0.806** | 1.000 | | |
| $F_{ta}$ | 0.752** | 0.780** | 0.806** | 0.713** | 0.904** | 1.000 | |
| T | 0.923** | 0.754** | 0.945** | 0.907** | 0.899** | 0.888** | 1.000 |

** Correlation is significant at the 0.01 level (2-tailed).

Table 3. Regression models for estimation of shrub fuel biomass.

| Dependent variables | Model form | Constant and coefficients | F | $R^2$ | Adj $R^2$ | SE |
|---|---|---|---|---|---|---|
| $F_{lf}$ | 1-) $Y = a + bH$ | a: 0.379, SE: 0.216<br>b: 0.027, SE: 0.02 | 195.368 | 0.879 | 0.874 | 0.650 |
| | 2-) $Y = a + bH \times VC$ | a: 0.721, SE: 0.094<br>b: 0.089, SE: 0.000 | 83.895 | 0.757 | 0.748 | 0.321 |
| $F_{ta}$ | 1-) $Y = a + bVC$ | a: -0.590, SE: 0.364<br>b: 0.031, SE: 0.05 | 41.944 | 0.608 | 0.594 | 0.441 |
| | 2-) $Y = a + bVC + cH$ | a: -0.182, SE: 0.356<br>b: 0.019, SE: 0.006<br>c: 0.045, SE: 0.02 | 30.226 | 0.699 | 0.676 | 0.394 |
| | 3-) $Y = a + bH \times VC$ | a: 1.036, SE: 0.123<br>b: 0.089, SE: 0.000 | 49.909 | 0.649 | 0.636 | 0.417 |
| | 4-) $Y = a + bH \times VC + cH^2$ | a: 0.689, SE: 0.157<br>b: 0.023, SE: 0.000<br>c: -0.058, SE: 0.000 | 37.180 | 0.741 | 0.721 | 0.365 |
| T | 1-) $Y = a + bH$ | a: 0.708, SE: 0.254<br>b: 0.028, SE: 0.02 | 155.107 | 0.852 | 0.846 | 0.764 |
| | 2-) $Y = a + bH \times VC$ | a: 1.123, SE: 0.191<br>b: 0.029, SE: 0.000 | 224.732 | 0.893 | 0.889 | 0.650 |

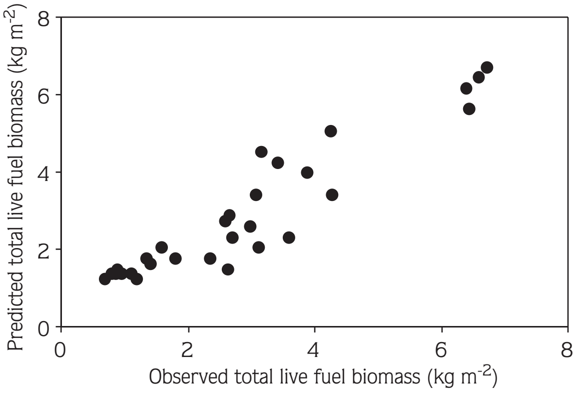

Figure 2. Relationship between predicted and observed total live fuel biomass.

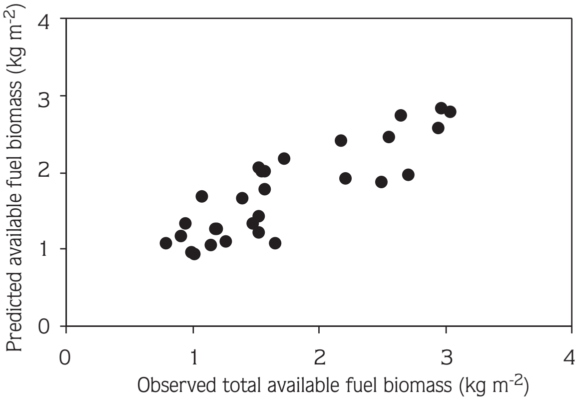

Figure 3. Relationship between predicted and observed total available fuel biomass.

(1993) and Specht (1969) provide similar data for Mediterranean evergreen sclerophyllous shrublands in Spain (2.2 kg m$^{-2}$). In other studies, it was reported that total biomass varied between 2.0 and 6.0 kg m$^{-2}$ (Basanta et al., 1988; Soto et al., 1997) in Atlantic gorse shrublands. In our study, total dead fuel biomass was very low in the diameter class, with an overall mean value of 13% of the total fuel biomass. A similar result was reported by Pereira (1995).

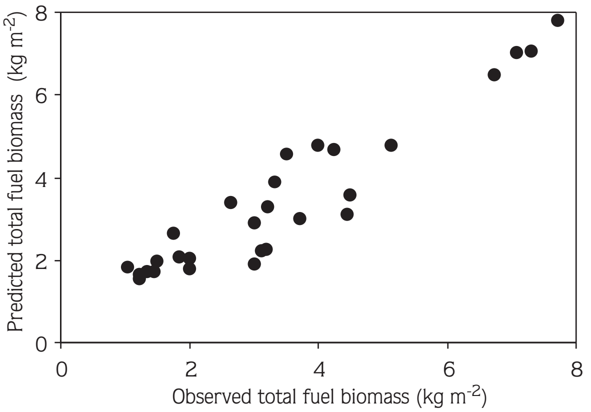

Figure 4. Relationship between predicted and observed total fuel biomass.

Correlation and regression analyses were undertaken to investigate the relationships between shrub properties and associated shrub components' biomass. Numerous studies on other fire-prone communities have established the relation between vegetation structure and fuel biomass. Although some authors have reported height to be a relatively poor predictor of biomass (Peek, 1970; Williams and McClenahen, 1984), the results from the present study showed that all biomass equations with height were highly significant for all components of shrubs (Table 2). Result of the correlation analysis indicated that total biomass was closely related to height and vegetation cover ($r = 0.923$, $r = 0.754$; $P < 0.01$). Similar results were found by Ohmann et al. (1976) and Buech and Rugg (1995). The correlations of vegetation height provided in our study also coincide with that described by Fernandes (1998) in Portuguese shrubland; the correlation of vegetation height with fine and total fuel loading was significant ($P < 0.0001$), with $r = 0.93$ and $r = 0.96$ respectively.

As a result, the linear relationships between biomass and H, VC, $H^2$, and H × VC were chosen as the best fitted equations to the predicted live, available, and total fuel biomass. These results are comparable to and agree well with those reported in the literature (Ohmann et al., 1976; Fogarty and Pearce, 2000).

Estimates of biomass and fuel loadings are required for many applications in the fields of fire management, ecology, biomass, and bioenergy research. However, the use of destructive sampling to provide these estimates is time consuming and expensive, and so collection of the number of samples required to give an accurate estimate is difficult to achieve (Fogarty and Pearce, 2000). This study, like several others, describes the development of relationships that enable rapid estimation of these biomass and fuel load components based on easily defined characteristics such as vegetation height and cover.

In conclusion, in this study carried out in *Quercus coccifera* L. dominated sites we developed a series of regression equations for predicting live fine fuel biomass, available fuel biomass, and total fuel biomass of certain shrub species common in western Turkey, including *Arbutus andrachne* L., *Pistacia lentiscus* L., and *Sarcopoterium spinosum*. The regression models developed herein are suitable for predicting fuel biomass in similar shrub areas. Local and site-specific fuel biomass data should be used for more reliable fire behavior predictions. Given the range of the data on which the relationships were based, this study provides a valuable contribution to biomass research in general. However, it should be kept in mind that the range of fuel characteristics on which the relationships were based represents the range of conditions under which it is possible to use the relationships generated through this study.

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