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Allometric equations for estimating standing biomass of *Avicennia marina* in Bushehr of Iran

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Abstract*:* Today, it is important to use of ecological indicators, such as biomass for recognizing the special status of ecosystems, such as mangrove forests and also monitoring and evaluating changes through a specific period. Because using the direct method of evaluating biomass would be destructive, it is common in all similar area to use determine exact Allometric equations by using the statistical relationship between the structural characteristics of trees and their biomass and use these equations to estimate the biomass of trees. The aim of this study is estimate the aboveground biomass of mangroves and determine Allometric models for Nayband area in Bushehr, located in southern Iran. A number of mangrove trees were randomly selected. Collar diameter, crown diameter and tree height of standing trees were measured. After logging and weighing fresh weight, dry weight, trunk and branches were obtained in laboratory and biomass of components was calculated. The relationship between quantities feature of trees and biomass for determination of allometric equation was studied by using linear, power and exponential regression. The equations were compared with each other based on the different modeling parameters. The highest significant correlation was found between crown diameters and dry weight ($R > 0.90$). The best equations were obtained by means of an exponential and power regression models ($R^2_{adj} > 0.90$). The models were obtained from explained factor, suggests that there might be a relationship between the characteristics of mangrove trees and biomass.

Key words: Biomass, mangrove, modeling, Iran

İran Buşehr Eyaletinde *Avicennia marina* biyokütle tahmini için allometrik denklemlerin kullanımı

Özet: Günümüzde; subasar ormanları gibi özel yapıdaki ekosistemlerin araştırılması için biyokütle gibi bazı ekolojik göstergelerin kullanılması önemlidir. Biyokütlenin hesaplanmasında doğrudan metodların kullanılması yıkıcı sonuçlar doğuracağından, ağaçların yapısal özellikleri ve biyokütle arasındaki istatistiki ilişkiye dayanan kesin Allometrik denklemleri kullanarak biyokütleyi tahmin etmek yaygın bir şekilde uygulanmaktadır. Bu çalışmanın amacı, İran'ın güneyinde yer alan Buşehr Eyaleti Nayband bölgesi'ndeki subasar ormanları yerüstü biyokütle miktarının Allometrik yöntemlerle belirlenmesidir. Subasar ormanlarında ağaçlar rastgele seçilmiş, bu ağaçların boyu, göğüs çapı ve taç genişlikleri ölçülmüştür. Kesilen ağaçların taze ve kuru ağırlıkları ölçülerek gövde ve dalları biyokütlelerinin hesaplanması için laboratuvara taşınmıştır. Uygun allometrik denklemin belirlenmesi için ağaçların özelliği ve biyokütle arasındaki ilişki doğrusal, güç ve üstel regresyon kullanılarak incelenmiştir. Denklemler farklı modelleme parametrelerine dayanarak birbirleriyle karşılaştırılmıştır. En yüksek anlamlı ilişki taç çapları ve kuru ağırlık ($R> 0.90$) arasında bulunmuştur. En iyi denklemler üstel ve güç regresyon modelleri ($R^2_{adj}> 0.90$) vasıtasıyla elde edilmiştir. Açıklanan gerekçelere dayanılarak kullanılan en uygun modeller; subasar ormanlarında yetişen ağaçların karakteristikleri ile biyokütle arasında bir ilişki olabileceğini bize düşündürmektredir.

Anahtar Kelimeler: Biyokütle, subasar orman, modelleme, İran

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1. INTRODUCTION

Mangroves are evergreen and saline tolerant forests, which grow on tidal beaches, tidal estuaries and swamps in tropical and semi-tropical areas (Sandilyan and Kathiresan, 2012). All parts of these habitats are compatible to conditions of high salinity, wind, anaerobic soil environment and high tides (Sandilyan et al, 2010; Sandilyan, 2010). The total area of these forests has declined from 18.8 million ha in 1980 to 15.2 million ha in 2005, which are distributed in 123 countries and zones (FAO, 2008).

Mangrove forests system is in constant jeopardy. In recent years, these vital ecosystems have had experienced several risks due to human activities and ignoring as well as natural disasters (Sandilyan and Kathiresan, 2012). Effects of this destruction trend on human life and the biodiversity have prompted many countries to consider various conservation and restoration programs using preventive measures and the application of innovative management techniques in order to achieve sustainable development. Meanwhile, the "ecosystem approach" is a strategy for integrated management of water resources, land and livelihood and natural ecosystem management based on it would be probable by environment conservation and recognition of economic exploitation, considering people's role and especially local communities as part of the ecosystem as well as taking into account the relationship between different parts of the ecosystem.
It is obvious that the preservation of the environment is not only the responsibility of an independent organization and the continuation of the relationship between human and nature as well as the convergence of power and determination of human communities, government and non-governmental authorities are a suitable basis for providing environmental protection and sustainable development (Sandilyan and Kathiresan, 2012). One of the forest ecosystems that are considered in this study is a mangrove forest. These ecosystems are considered as ecotones between aquatic and terrestrial environments (Ghasemi and Sousa, 2008; Smith et al, 2013).

The area of this particular type of forest is 25,760 ha in Iran; while the total area of mangrove forests is 13,776,000 ha in the world (Giri et al., 2011). The performance of mangroves and mangrove stands' structures have been clearly affected by industries in recent decades and its frequency is declining. Mangrove loss can be due to the several reasons including changing tidal regime, salinity, pH and nutrient levels (Farley et al 2010). It of the above ground biomass (AGB) is an important analysis in evaluating the carbon storage, and its impact on forest degradation.

Biomass is the total of all parts of a tree including aboveground and underground parts consisting of roots, trunk, branches, leaves, flowers and fruits (Hogarth, 2015). Accurate estimates of biomass are important for describing the current state of mangrove forests and for predicting the consequences of change (Steinke *et al*., 1995; Comley and McGuinness, 2005).

Mangroves in Iran are often shorter, wider with multi-branches compared to tropical trees. Allometric equations for estimating biomass, with an emphasis on tree height, will not be able for short mangrove tress of Bushehr. The purpose of this study was to develop Allometric models for aboveground compartments of mangrove trees. In mangrove tree models of New Zealand (Woodroffe, 1985), South Florida (Coronado-Molina et al, 2004; Ross et al 2001) and Iran (Safdari and Shadman, 2013), crown diameter and tree height are used in allometric equation for estimating the aboveground biomass. Many researchers have developed relations to predict above-ground biomass using DBH for mangroves from a variety of areas (Saenger and Snedaker, 1993; Smith III and Whelan, 2006). However, no allometric equations have been developed for mangroves in Iran.

In this study we tried to provide necessary research outlines for management of these habitats by identifying structural properties and biomass of mangrove habitat and also achieving the most optimal model for estimating biomass. The main aim of this study was to evaluate biomass of mangrove forests in the protected area of Bushehr, located in southern Iran, in order to achieve the management objectives and sustainable efficiency of their ecological function. The purpose of this work was to develop allometric relations for leaves, stems, branches and above-ground biomass on Collar diameter, crown diameter and tree height for an *A. marina* forest in Bushehr, located in southern Iran.

2. MATERIAL AND METHODS

2.1 Material

This study was conducted in mangrove forests in the protected area of Bushehr, located in southern Iran, which has an area of 225 ha (Figure / Şekil 1). This area is located between 27° 23' 53" to 27° 29' 33" north latitude and 52° 34' 54" to 52° 41' 17" east longitude. The annual temperature is higher than 24 °C for eight months and not less than 15 °C during the year. In addition, according to the 27-year- old data, the annual rain fall of Asaloye station is 193.3 mm. The climate of the study area is subtropical tends to dry tropical and it is located in hot and intense desert according to Emberger climate classification. Soil is derived from alluvial sediments and becomes saline and limestone towards the sea.

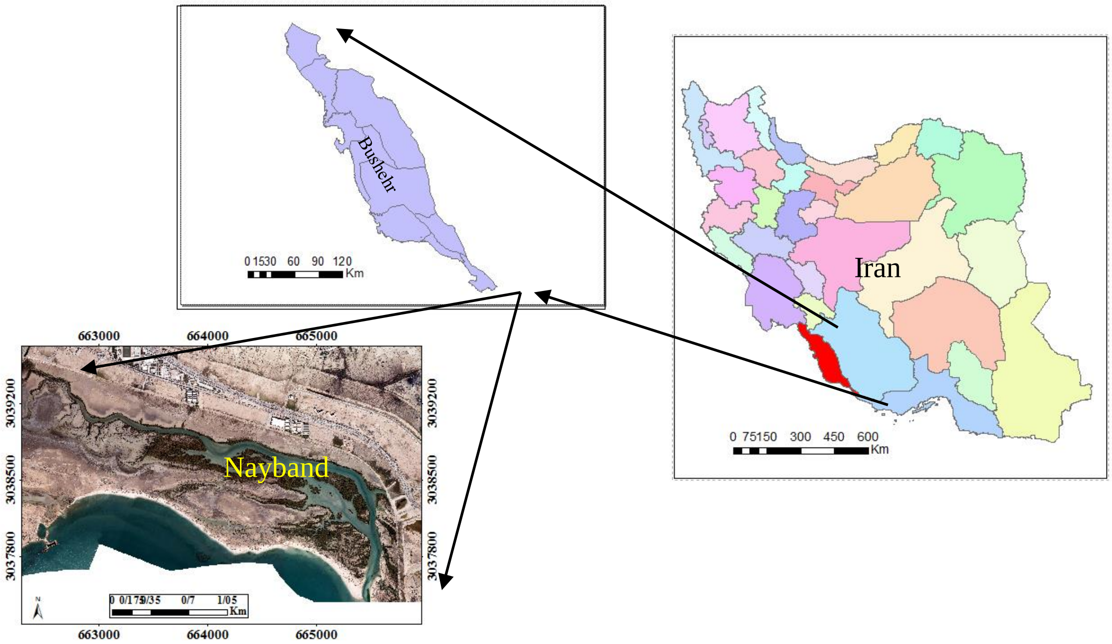

Figure 1. Map showing site location
Şekil 1. Çalışma alanı

2.2 Methods

Since mangrove forests of located in southern Iran, in are considered as protection and conservation forests and not commercial, the growth characteristics were measured in order to use in structural description. Tree height was measured. Canopy was calculated through measuring the two diameter perpendicular of the crown in centimeter by a measuring tape and then the average crown diameter was used in the calculations (Osland et al, 2014). Trunk diameter at the stem base was measured in centimeter. It should be noted that the swamps in the mangroves habitat and coppice trees made the measuring of diameter at breast height difficult and sometimes impossible. Thus, the tree diameter was measured at 30 cm from the ground. Today, it is important to use of ecological indicators, such as biomass for recognizing the special status of ecosystems, such as mangrove forests and also monitoring and evaluating changes through a specific period. Because using the direct method of evaluating biomass would be destructive, it is common in all similar area to use determine exact Allometric equations by using the statistical relationship between the structural characteristics of trees and their biomass and use these equations to estimate the biomass of trees. A number of mangrove trees in Bushehr, located in southern Iran, were randomly selected. Collar diameter, crown diameter and tree height of standing trees were measured. After logging and weighing fresh weight, dry weight, trunk and branches were obtained in laboratory and biomass of components was calculated. The relationship between quantities feature of trees and biomass for determination of allometric equation was studied by using linear, power and exponential regression.

3. RESULTS

Mangroves wood density was obtained 0.69 g/cm^2. The results of fitting different variables with various regression models for estimating leaf dry weight showed that regardless of the variables used in the model, exponential model and power model were always better than the linear model in terms of modeling. The results of fitting different variables used to estimate the dry weight of branches and tree trunks indicated that the exponential model often had a better fit to the data. Among independent variables for modeling, the best of them were collar diameter, canopy diameter and height, respectively (Table / Tablo 2).

Table 1. Results of regression analysis to determine a model for estimating leaf dry weight
Tablo 1. Yaprak kuru ağırlığı tahmin edilmesinde kullanılan model için regresyon analizi sonuçları

equation	**Std. Error**	**Sig.**	**F**	**R^2 adj**	**Model**	**Independent variable**
Y= 69/25*d-55/712	189/07	0/000	195/99	0/95	linear	collar diameter (cm)
Y= 113/83* $d^{0/84}$	0/21	0/000	108/84	0/92	power	
Y= 365/54+$e^{0/058d}$	0/19	0/000	133/99	0/93	exponential	
Y= 566/75*H-314/036	400/25	0/000	36/74	0/78	linear	Total height (m)
Y= 338/58* $H^{1/212}$	0/27	0/000	60/72	0/86	power	
Y= 248/77+$e^{0/50H}$	0/25	0/000	72/73	0/88	exponential	
Y= 582/83*CD-373/79	249/64	0/000	108/58	0/92	linear	canopy diameter (m)
Y= 322/79 *$CD^{1/255}$	0/20	0/000	127/42	0/93	power	
Y= 248/45+$e^{0.5CD}$	0/18	0/000	159/80	0/94	exponential	

Y: leaf dry weight (g), x: independent variable, $R^2_{(adj)}$: adjusted coefficient of determination, F: analysis statistic.

Table 2. Results of regression analysis to determine a model for estimating branches and trunks weights
Tablo 2. Dal ve gövde ağırlığı tahmin edilmesinde kullanılan model için regresyon analizi sonuçları

Equation	**Std. Error**	**Sig.**	**F**	**R^2 adj**	**Model**	**Independent variable**
Y= 3614/39*d-11498/2	11238	0/000	151/05	0/94	linear	collar diameter (cm)
Y=2072/07*$d^{1/088}$	0/24	0/000	134/06	0/93	power	
Y= 9136/5+$e^{0/08d}$	0/09	0/000	977/87	0/99	exponential	
Y= 29200/8*H-29812/44	22597	0/000	30/16	0/75	linear	Total height (m)
Y= 8451/07 *$H^{1/57}$	0/32	0/000	71/84	0/87	power	
Y= 5524/8+$e^{0/66H}$	0/25	0/000	130/67	0/93	exponential	
Y= 29962/09*CD-32715/12	16115	0/000	68/85	0/88	linear	canopy diameter (m)
Y= 8060/45* $CD^{1/61}$	0/25	0/000	124/49	0/92	power	
Y= 5602/50+$e^{0.65CD}$	0/15	0/000	159/80	0/98	exponential	

Y: branches and trunks' dry weight (g), x: independent variable, $R^2_{(adj)}$: adjusted coefficient of determination, F: analysis statistic.

The results of fitting power and exponential models to estimate dry weight of aboveground revealed that the exponential model was more appropriate and had better results using canopy diameter and collar diameter as independent variables (Table / Tablo 3). Collar diameter and canopy diameter were the most proper variables to predict the aboveground biomass. The best and worst regression models were the exponential model based on the collar diameter and linear model based on the total height, respectively.

Table 3. Results of regression analysis to determine a model for the above ground dry weight
Tablo 3. Kuru ağırlığın tahmin edilmesinde kullanılan model için regresyon analizi sonuçları

Equation	Std. Error	Sig.	F	R^2 adj	Model	Independent variable
Y= 3683/6*d-11442/5	11375	0/000	153/19	0/94	linear	collar diameter (cm)
Y= 2174/04*d $^{1/08}$	0/24	0/000	136/44	0/93	power	
Y= 9498/05+e$^{0/76d}$	0/09	0/000	1013/1	0/99	exponential	
Y= 29767/5*H-30126/5	22972	0/000	30/77	0/75	linear	Total height (m)
Y= 8787/18*H $^{1/56}$	0/32	0/000	72/45	0/88	power	
Y= 5763/7+e$^{0/66H}$	0/24	0/000	131/03	0/93	exponential	
Y= 30544/9*CD-33088/9	1633	0/000	69/68	0/87	linear	canopy diameter (m)
Y= 8380/9* CD$^{1/6}$	0/25	0/000	127/19	0/93	power	
Y= 5841/98+e$^{0.64CD}$	0/14	0/000	397/73	0/98	exponential	

Y: total dry weight of aboveground (g), x: independent variable, $R^2_{(adj)}$: adjusted coefficient of determination, F: analysis variance of statistic, Std. Error: standard error of the model, Sig: significance level

By comparing different variables in the model of dry weight and total height, it was inferred that the collar diameter and canopy diameter of mangrove trees are generally the variables that justify the greater proportion of dry weight of tree parts and total dry weight of the tree. In Figures / Şekil 1, 2 and 3, the cloud points and fitted curve are shown for each of the different parts the tree based on the independent variables of collar diameter, Total height and canopy diameter.

4. DISCUSSION

In this study, different variables of collar diameter, canopy diameter and total tree height as independent variables were compared to estimate leaf dry weight, trunk dry weight and aboveground dry weight of *Avicennia marina*. The results showed that the leaf dry weight, trunk dry weight and total dry weight of tree could be estimate using the collar diameter and canopy diameter as independent variables. Diameter, stem height and crown diameter are excellent predictors of total above ground biomass for mangrove forest (Saenger and Snedaker, 1993; Smith and Whelan, 2006). The reason that the collar and canopy diameters were best independent variables for estimating dry weight is that these variables exactly reflect the dependent changes, which can be explained by two cases. First, the canopy structure of mangrove trees is circular and canopy diameter represents the circle diameter. Tree height can also be a representative, but due to changes caused by the trunk height in measured trees was more than the dry weight, hence modeling index showed weaker results. Second, the trunk dry weight usually consists 60% of the total dry weight (according to the measurement results of this study), which the aerial dry weight could well be justified on the basis of collar diameter. The comparison of linear, power and exponential models for modeling above ground dry weight and tree compartments based on collar diameter, canopy diameter and total tree height indicated that the exponential and power model gave better results ($R^2_{adj}> 0.90$) than linear model. A more slope was observed in the exponential model and increasing in x caused the greater increasing in y, which was true for mangrove trees. Regarding the structure of mangrove trees that by increasing in tree size, the slope did not accelerate, the initial changes were not high.

A lot of researches have been done to determine different models and to choose the independent variable, which power and exponential models were often introduced based on the diameter at breast height and canopy diameter (Hogarth, 2015; Komiyama et al., 2008; Parvaresh et al 2012; Safdari and Shadman, 2013). Mangroves' wood density was obtained 0.69 g/cm2, which was close to the results of Safdari and pormosa (2013) (0.64 g/cm^2).

5. CONCLUSIONS

In summary, Allometric equations of aboveground biomass of mangrove trees are used to calculate: (1) aboveground biomass; (2) trunk biomass; and (3) leaf biomass. Dry weight of trees is introduced as a prediction in equations. Ecologists predict challenges through structural characterization and monitoring ecotones. Such equations can be used in natural sciences in order to monitor ecological changes associated with dynamics and climate changes of mangrove forests located in Bushehr province. Furthermore, this conforms to the viewpoint of Steinke *et al*. (1995), Smith and Whelan (2006) that most allometric relations cannot be applied without modification for local mangrove stands

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