Uncertainties Brought by Weight Assignment in Ecosystem Health Modelling

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Abstract: Weight assignment is the most important step in ecosystem health modelling. However, few researches were conducted to test the uncertainties brought by weighting methods in ecosystem health modelling. In this research, aimed to test the rationality and uncertainties brought by objective weighting methods, we made a comparison between different objective weighting methods (Entropy, Variation coefficient, Mean square error, Critic). We found that (1) the weights assigned by different objective method are quite different; (2) the variation of sample size does not exert significant influences on weight assignment. However, the weight of indicator has the tendency of increasing or decreasing with the increment of sample size; (3) the weights assigned by these four objective methods were not able to reflect the actual relative importance of indicators. Therefore, we don't advise to use objective weighting method as the sole approach to assign the weight of indicator in ecosystem health modelling.
Key words: Entropy; Variation coefficient; Mean square error; Critic; Plant height; Basal diameter.

1. Introduction

Ecosystem health modelling is of great importance for ecosystem management. It has become one of the hot fields in researches of macro-ecology [1]. Approaches of indicator species and indicator system were widely used in ecosystem health modelling. Compared with indicator species, indicator system could reflect the status of complicated ecosystem more comprehensively than that of indicator species [2]. For indicator system, weight assignment is the key step in the procedure of ecosystem health modelling. Methods of weight assignment were divided into two types: subjective and objective. Delphi and AHP (Analytic Hierarchy Process) are typical subjective methods [3-6]. Entropy method [7,8], variation coefficient method[9], mean square error method [10] and Critic method [11,12] are four objective methods which were often employed to determine the indicator weight in researches of ecosystem health modelling.

Some researchers deemed that the weight assigned by objective method could reflect the real relationship between different ecological elements [13]. However, some researchers put forward the opinion that the weight assigned by objective method was greatly influenced by the data and it cannot represent the relative importance of specific indicator [14]. With regard to the subjective method, some researchers deemed that it could reflect the relative importance of different indicators [15]. However, some researchers considered that the weight assigned by subjective method was easily affected by the personal professional background, and the importance of indicators might be exaggerated or over degraded [14]. Therefore, we should pay more attention to the uncertainties brought by weighting methods in ecosystem health modelling.

Mangrove forest is located in the upper tidal zone of tropics and subtropics. It is the habitat of numerous species and one of the ecosystems with highest diversity in the world [16]. In past decades, more than 35 % of the mangrove forests in the world were destroyed for human distubance [17]. In China, the area of mangrove forest dropped from 42 001 hm^2 in the 1950s to 22 024.9 hm^2 in 2000 [18]. From 2000 to now, large area of mangrove forests were reconstructed in China. And the area of mangrove forest increased to 34 472.14 hm^2 in 2013 [18]. The health status and stability of these planted mangrove forests have become a common concern of the government and the local people. Therefore, health assessment of planted mangrove forest has become an important direction in researches of ecological conservation in China.

Plant height and basal diameter are important indicators of plant morphology. They are widely used in the modelling of forest ecosystem health [19]. In this research, a case study was performed in Beilun River National Reserve of Guangxi Province in China to assess the uncertainties brought by weighting methods. We hope this research could provide some references for ecosystem health modelling and benefit the ecosystem management.

2. Data and method

2.1 Study area

Beilun River National Reserve is located in Guangxi province, Southern China (Figure 1) and the total area is 3000 ha. This reserve was established in 1985 and the main protection target is mangrove ecosystem. In the history, large area of the mangrove forests in this reserve were destroyed and turned into shellfish beds. In recent years, mangrove forests dominated by *Kandelia candel* were re-constructed in this reserve.

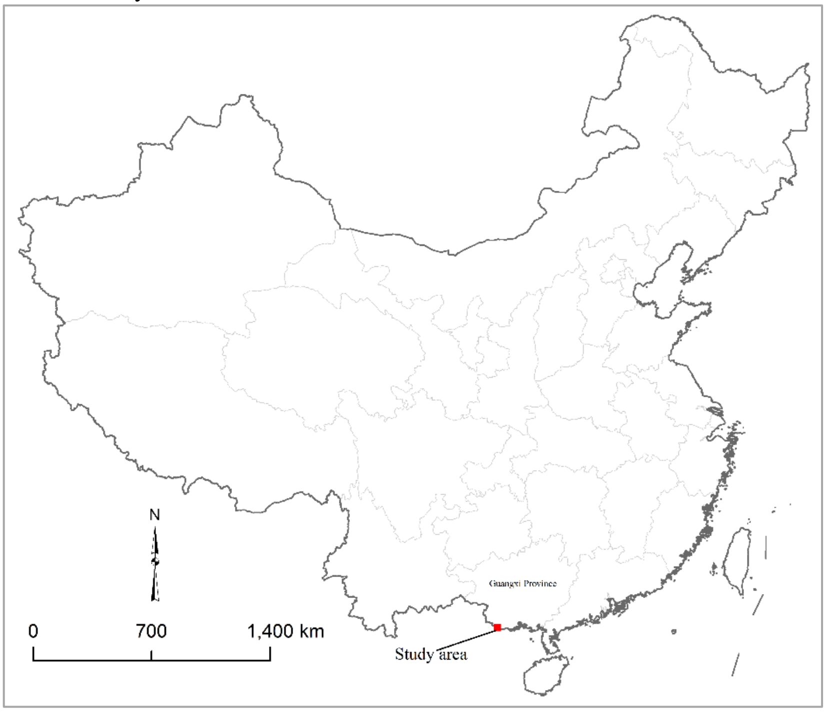

Figure 1. Location of the study area

2.2 Data collection

In the nature, the seeds of *Kandelia candel* germinate in the fruit and falling to silt tidal flat and become a new plant in the middle of May. Cultivated seedlings in nursery garden almost develop at the same tempo as the natural seedlings. In the study area, the cultivated seedlings were transplanted to the silt tidal flat in the middle of May in 2016.

The measurements of plant height and basal diameter were conducted in the artificial reconstructed area (ARA) and natural propagation area (NPA). Eight plots (5 m × 5 m) were randomly set in the ARA and NPA separately. A tag was attached to each seedling in the plots. The first survey was performed in the October of 2016. Total 265 planted seedlings and 212 natural seedlings were surveyed. The second survey was performed in the July of 2017. 211 planted seedlings and 175 natural seedlings were surveyed. Figure 2 is the data description of plant height and basal diameter of planted seedlings surveyed in 2017.

2.3 Data analysis

2.3.1 Analysis on the change of plant height and basal diameter

Independent sample Test was used to compare the difference of plant height and basal diameter between the planted seedlings and natural seedlings ($P < 0.05$).

We also cacualted the ratio of plant height (cm) to basal diameter (mm) to describe the morphological characteristics of mangrove seedlings.

2.3.2 Ecosystem health modelling

(1) Data normalization

Plant height and basal diameter were regarded as positive indicators in previous researches of ecosystem health modelling [19]. They were normalized according to the following equation:

$$X_s = (X_i - X_{\min}) / (X_{\max} - X_{\min})$$

where X_s is the data after normalization, X_i is the raw sample data associated with indicator *i*, and X_{min} and X_{max} are the minimum and maximum value of the sample data of indicator *i*.

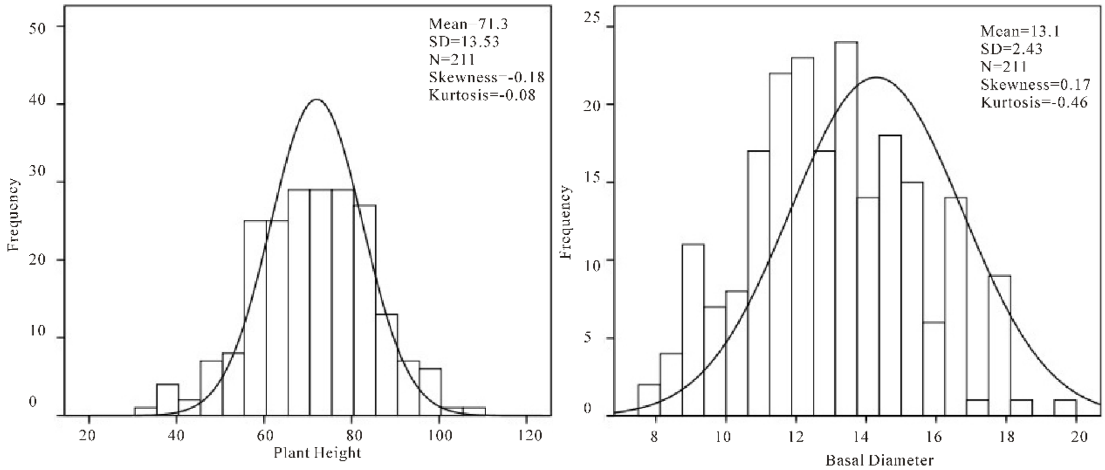

Figure 2. Data description of plant height and basal diameter of planted seedlings surveyed in 2017

(2) Weight assignment

Entropy method, variation coefficient method, mean square error method and critic method were used to calculate the weight of plant height and basal diameter based on the survey data of planted seedlings.

In order to investigate the influences of sample size on the weight assignment, a serial of data sets with different amount of records (10,30,50,70,90,100,120,150,170,190,210) were fromed to calculate the weight.

The caculation of the weight was conducted according to the following procedure.

Entropy method:

1) The raw data matrix was normalized into standard data matrix $R=(r_{ij})_{m\times n}$; where r_{ij} represents the original value of the jth (j = 1, . . . , n) indicator of the ith object (i = 1, . . . , m).

2) The entropy of the j_{th} indicator was defined as

$$H_j=-k\sum_{i=1}^{m} f_{ij}\ln f_{ij}\,,\quad f_{ij}=r_{ij}\Big/\sum_{i=1}^{m} r_{ij}\,,\quad k=1/\ln m$$

Where f_{ij} is the proportion of the value of the j_{th} indicator of i_{th} object in the total value of indicator j_{th}.

3) The weight of the jth indicator was defined as

$$W_j=(1-H_j)\Big/(n-\sum_{j=1}^{n} H_j)\ \text{, Where }\ 0\le W_j\le 1,\ \sum_{j=1}^{n} W_j=1.$$

Variation coefficient method:

1) The raw data matrix was normalized into standard data matrix $R=(r_{ij})_{m\times n}$; where r_{ij} represents the original value of the jth (j = 1, . . . , n) indicator of the ith object (i = 1, . . . , m).

2) The variation coefficient of the jth indicator was defined as $\delta_j=\sigma_j\Big/\left|\overline{r_j}\right|$, where σ_j is the mean square error of the jth indicator,

$$\sigma_j=\sqrt{\frac{1}{m}\sum_{i=1}^{m}(r_{ij}-\overline{r_j})^2}\ ,\quad \overline{r_j}\ \text{ is mean value of the } j\text{th indicator, }\ \overline{r_j}=\frac{1}{m}\sum_{i=1}^{m} r_{ij}\ .$$

3) The weight of the jth indicator was defined as

$$W_j=\delta_j\Big/\sum_{j=1}^{n}\delta_j$$

Mean suqare method:

1) The raw data matrix was normalized into standard data matrix $R=(r_{ij})_{m\times n}$; where r_{ij} represents the original value of the jth (j = 1, . . . , n) indicator of the ith object (i = 1, . . . , m).

2) The mean square error of the jth indicator was defined as

$$\sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)^2}$$, where $\bar{r}_j$ is mean value of the *j*th indicator, $\bar{r}_j = \frac{1}{m}\sum_{i=1}^{m} r_{ij}$.

3) The weight of the *j*th indicator was defined as

$$W_j = \sigma_j \Big/ \sum_{j=1}^{n} \sigma_j$$

Critic method:

The critic method determines the weight based on the relative importance and the conflict between indicators.

1) The raw data matrix was normalized into standard data matrix $R = (r_{ij})_{m\times n}$; where r_{ij} represents the original value of the *j*th (*j* = 1, . . . , *n*) indicator of the *i*th object (*i* = 1, . . . , *m*).

2) The weight of the *j*th indicator was defined as

$W_j = C_j \Big/ \sum_{j=1}^{n} C_j$, where $C_j = \sigma_j \sum_{k=1}^{n}(1 - COR_{jk})$, where COR is the correlation coefficient between indicator *j* and *k*, and σ_j is the mean square error of the *j*th indicator,

$\sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)^2}$, $\bar{r}_j$ is mean value of the *j*th indicator.

3. Results

3.1 Comparison of morphological characteristics between natural and planted seedlings

The independent sample test indicated that (Figure 3 and Figure 4) in 2016, the height of planted seedlings is significantly higher than that of natural seedlings (F = 0.00; p < 0.05). There is no significant diference in the basal diameter between planted and natural seedlings (F = 5.91; p = 0.53). In 2017, the plant height and basal diameter of planted seedlings are higher than that of natural seedlings (p < 0.05).

The ratio of plant height to basal diameter of planted seedlings is 4.89 in 2016 and increased to 5.53 in 2017 (Figure 5). On the contrary, the ratio decreased from 4.54 in 2016 to 4.22 in 2017 for natural seedlings (Figure 5). The independet samples test indicated that the differences in the ratio of plant height to basal diameter between planted and natural seedlings in 2016 and 2017 are both significant (p < 0.05).

3.2 Comparison between the weight of plant height and basal diameter

The weight of plant height and basal diameter fluctuated with the change of sample size (Figure 6). The variance analysis showed that the weights of plant height assigned by all the methods are significantly higher than that of basal diameter under variant sample size (p < 0.05) (Figure 6 and Figure 7).

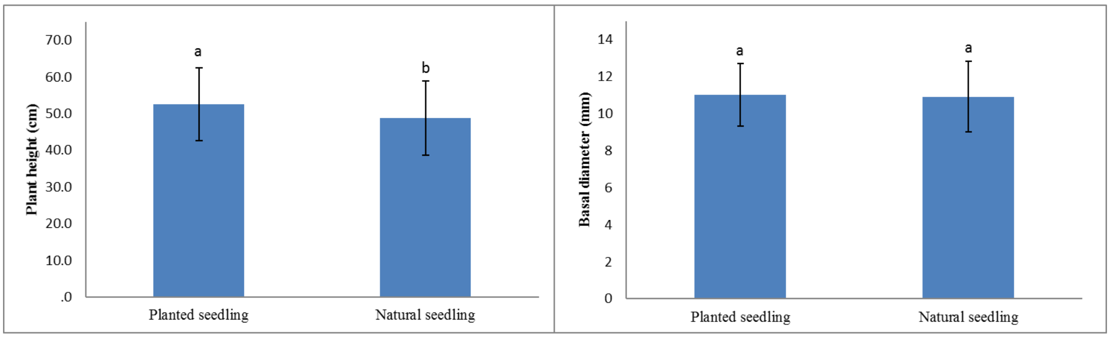

Figure 3. Comparision of plant height and basal diameter between planted seedlings and natural seedlings based on the survey data of 2016 (Mean±SD, different superscripts differ significantly)

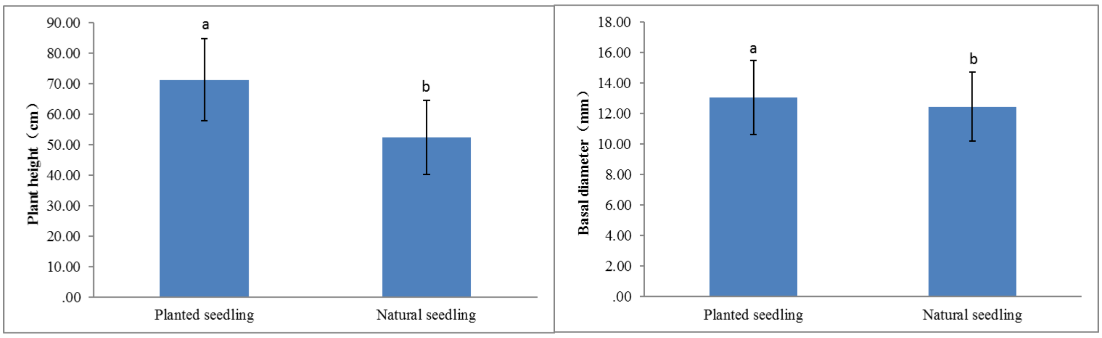

Figure 4. Comparision of plant height and basal diameter between planted seedlings and natural seedlings based on the survey data of 2017 (Mean±SD, different superscripts differ significantly)

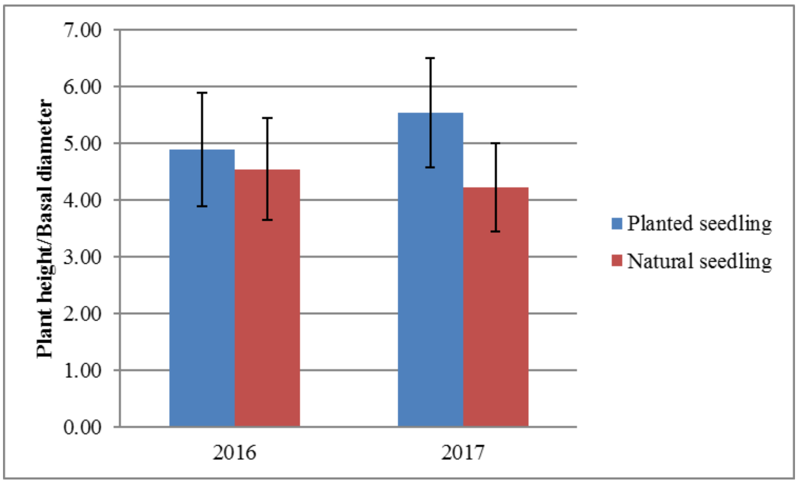

Figure 5. Comparison of the ratio of plant height to basal diameter between planted seedlings and natural seedlings based on the survey data of 2016 and 2017 (Mean±SD)

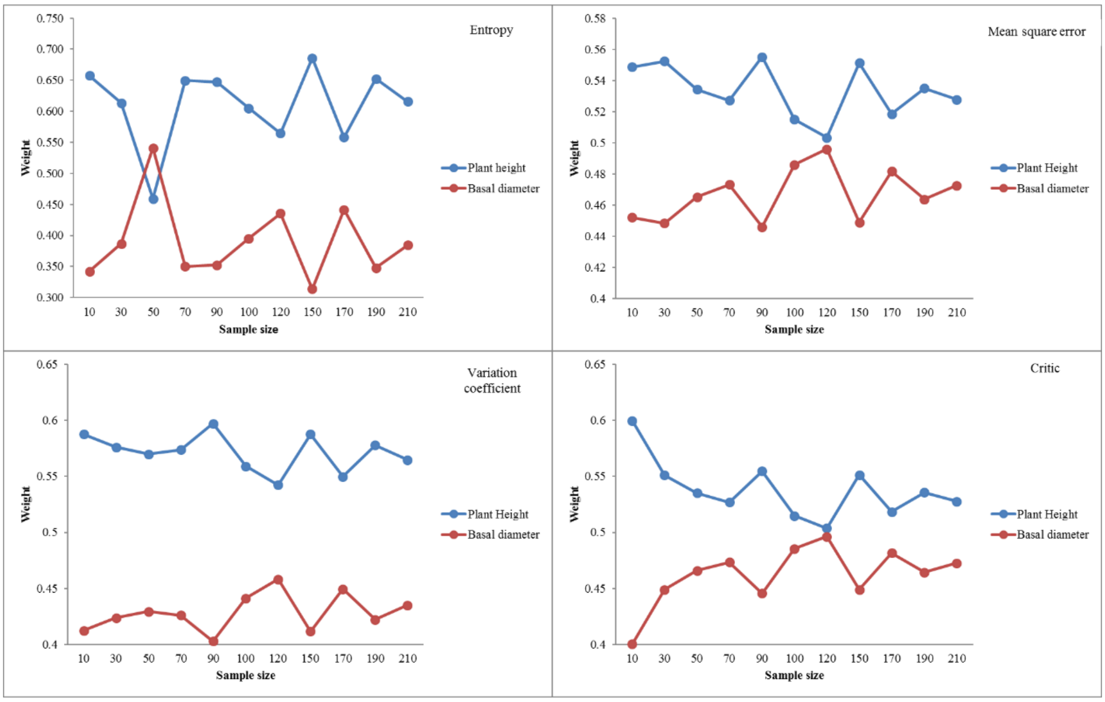

Figure 6. The dynamics of the weights assigned by different methods under variant sample size

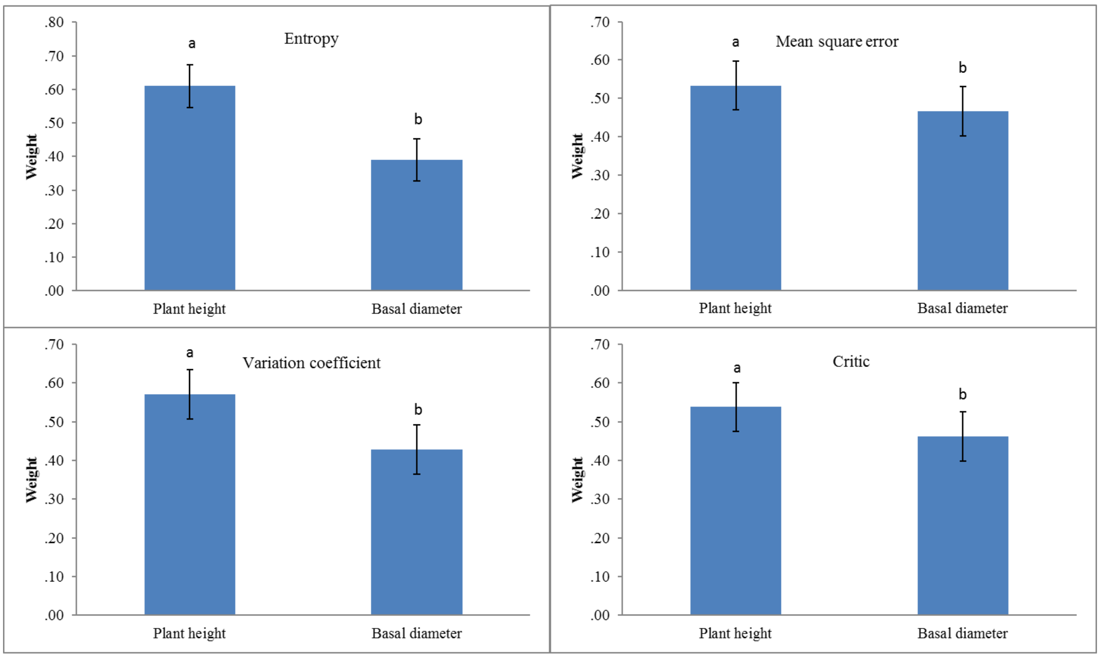

Figure 7. Comparison between the weight of plant height and basal diameter assigned by different methods under variant sample size (Mean±SD, different superscripts differ significantly)

3.3 Comparison of the weights assigned by different weighting methods

The weights of plant height determined by entropy method and variation coefficient method are significantly higher than that of critic method and mean square error method ($p < 0.05$) (Figure 8). There is no significant differences between the weights of plant height determined by entropy method and variation coefficient method ($p > 0.05$) (Figure 8). And also, no significant differences existed between the weights of plant height determined by critic method and mean square method ($p > 0.05$) (Figure 8).

For basal diameter, the weights determined by critic method and mean square error method are higher than that of entropy method and variation coefficient method ($p < 0.05$) (Figure 9). There is no significant differences between the weights determined by entropy method and variation coefficient method ($p > 0.05$) (Figure 9), and also no significant differences between the weights determined by critic method and mean square method ($p > 0.05$) (Figure 9).

We can also see that the variance generated by entropy method, which was casued by the change of sample size, is significantly higher than that of other methods ($p < 0.05$, Figure 10 and Figure 11).

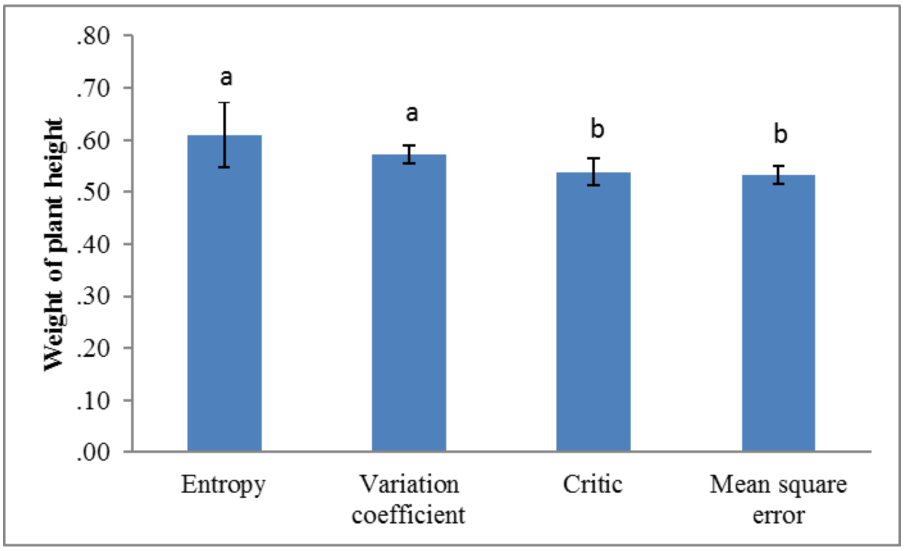

Figure 8. The mean weight of plant height determined by different methods under variant sample size (Mean±SD, different superscripts differ significantly)

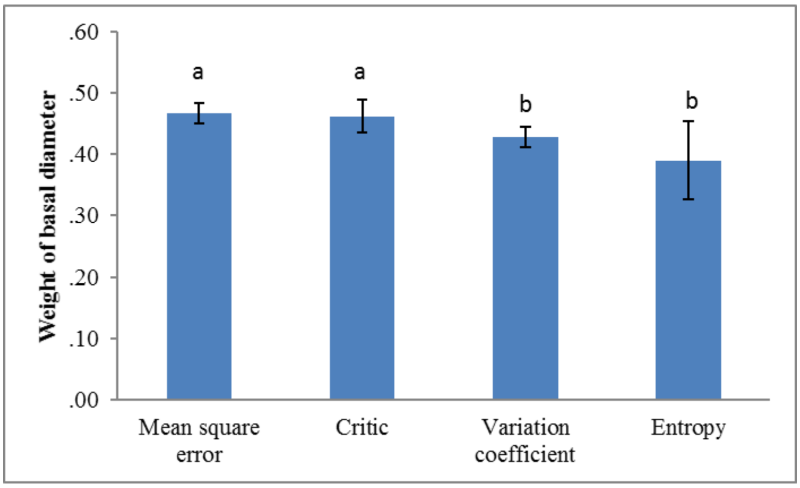

Figure 9. The mean weight of basal diameter determined by different methods under variant sample size (Mean±SD, different superscripts differ significantly)

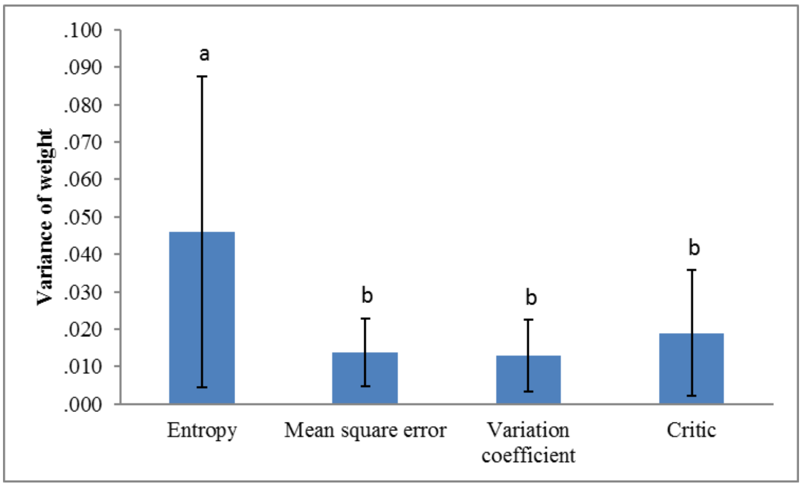

Figure 10. The mean variance of the weight of plant height generated by different methods under variant sample size (Mean±SD, different superscripts differ significantly)

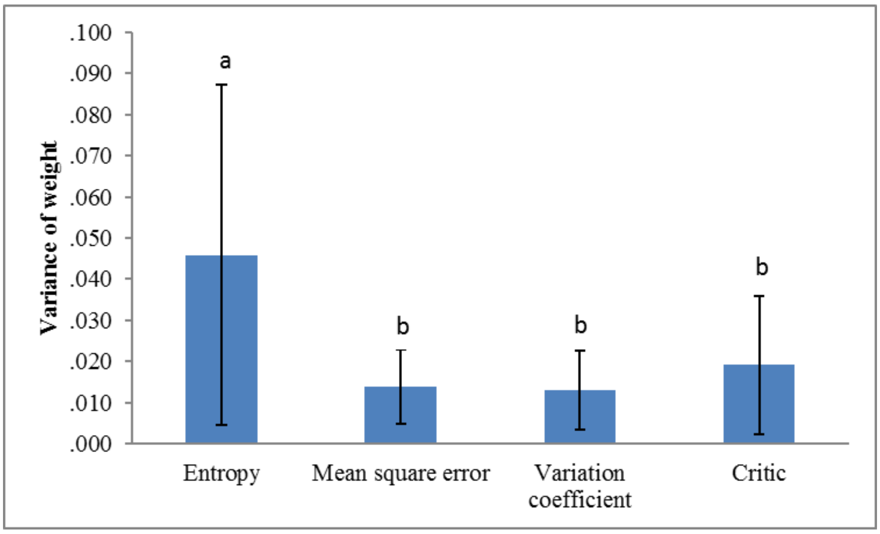

Figure 11. The mean variance of the weight of basal diameter generated by different methods under variant sample size (Mean±SD, different superscripts differ significantly)

3.4 The relationship between the weight and sample size

For the plant height and basal diameter, no significant relationships between the weight and sample size were found under variant methods ($p > 0.1$) (Figure 12 and Figure 13). However, the weight of indicator has the tendency of increasing or decreasing with the increment of sample size.

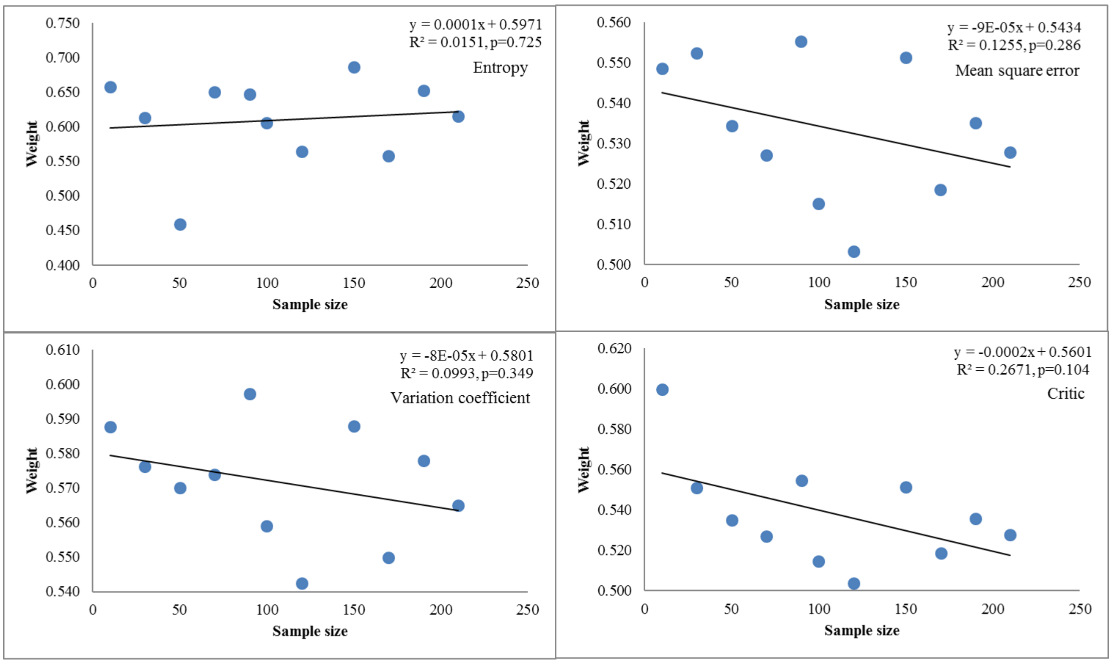

Figure 12. The relationship between the weight of plant height and samle size under variant weighting methods

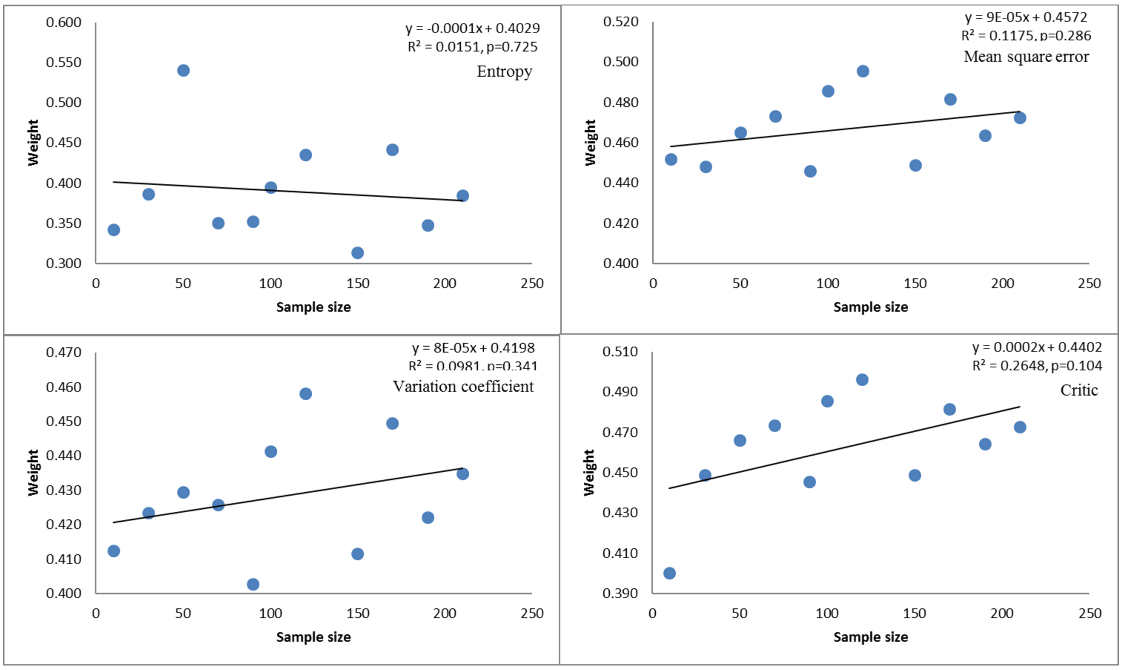

Figure 13. The relationship between the weight of basal diameter and samle size under variant weighting methods

4. Discussions

4.1 The relative importance of plant height and basal diameter

From the comparison of plant height and basal diameter between planted seedlings and natural seedlings, we can see that the plant height and basal diameter of planted seedlings are significant higher than that of natural seedlings (Figure 3 and Figure 4). The ratio of plant height to basal diameter of planted seedlings is higher than that of natural seedlings ($p < 0.05$) (Figure 5). This indicated that the planted seedlinds tend to grow tall and thin, and the natural seedlings tend to grow short and thick.

Wind and tide are the most important factors which influence the settlement and development of mangrove seedlings [20]. The seedlings with "short and thick" morphology possess more and stonger aerial roots or secondary roots, which could help the seedlings to resist the impacts of wind and tide, and survive on the mud flat [20]. Therefore, from this perspective, basal diameter plays a more important role in the survival of seedlings than that of plant height.

However, in this research, the weights of plant height determined by entropy, variation coefficient, mean square error and critic methods are all significantly higher than that of basal diameter (Figure 6 and Figure 7). And also, in some researches, plant height was regarded as more important than that of basal diameter [19]. This conflict reminds us that the relative importance of the same indicator might be different with the change of ecosystem or plant species. Evaluation on the role of indicators in specific ecosystem should be conducted to underpine the weight assignment in ecosystem health modeling.

4.2 Suggestions based on this research

Based on this research, we don't advise to use objective method as the sole approach to determine the weight of indicator in ecosystem health modelling. However, it is also diffcult for subjective methods to guarantee the rationality of the weight assignment, especially when numerious indicators are included in the modelling. Because, the thinking of expert is diffcult to be consistent throughout the process of weight assignment. Therefore, our recommendation is to use subjective method to determine the weight of macro-level indicators, and use objective method to provide data information to help the expert to judge the relative importance of micro-level indicators.

We need to be alert that the weights determined by variant objective methods could be quite different (Figure 8 and Figure 9). Comparison of different objective methods should be performed to help us to make the best judgement. We should also pay more attention to the influences of sample size on the weight assignment. Although no significant relatiohships between the weight and sample size were observed, the weight of indicator has the tendency of increasing or decreasing with the increment of sample size (Figure 12 and Figure 13). In addition to this, larger variation of weight exist when the sample size is small (Figure 6). Among these four methods in this reaearch, sample size exert more influences on the weight determination of entropy method (Figure 10 and Figure 11).

There are other objective mehods, such as artificial neural networks [13], principal component analysis [19] and knowledge granularity [21] employed to determine the weight of indicators in the modelling of ecosystem health. Limited by the data, these methods were not covered in this research. Further researches should be performed to assess the uncertainties of these methods in weight assignment.

5. Conclusions

The weights assigned by different objective methods are quite different. The variation of sample size does not exert significant influences on the weight assignment in this research, however, the weight of indicator has the tendency of increasing or decreasing with the increment of sample size. The weights assigned by entropy, variation coefficient, mean square error and critic method were not able to reflect the actual relative importance of indicators in the ecosystem health modelling of planted mangrove forest.

6. Acknowledgement

This research was finacianlly supported by the Ocean Public Welfare Scientific Research Project, China (No. 201505028-5-1).

7. References

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