



What factors are influencing peri-urban forest carbon storage in different land use types based on permanent plots from 2009–2018

Yanyan Wei^{1,2} · Min Zhao^{1,2} · Jun Gao^{1,2}

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Abstract

Urban forests are crucial in reducing atmospheric carbon dioxide (CO₂) concentrations. Forest structure and composition in particular are important indicators influencing forest carbon storage. In this study, a long-term survey in Chongming Island was used as a case study to examine temporally the changes in an urban forest and its assemblage of woody plant specifically during 10 years. We measured species evenness, species diversity, canopy cover, tree density and aboveground carbon storage (ACS) in three broad land use types including agriculture uses (ALU), forest land uses (WLU), and constructed land uses (CLU). Using field data from long-term permanent plots and structural equation modeling (SEM), the objective of the study was to estimate the direct and indirect effects of these metrics on ACS across these three land use types. The study showed that species evenness, species diversity, canopy cover, and tree density all increased in the ALU, WLU, and CLU. Meanwhile, the tree ACS was higher than shrub ACS. Average ACS increased by 2.07, 9.89, 4.06 MgC/ha in CLU, ALU, CLU, respectively. Both key dominant species, *Cinnamomum camphora* and *Metasequoia glyptostroboides* played critical roles in determining ACS. Vegetation density strongly directly affected on ACS in WLU, whereas canopy cover exerted the similar effect on ACS in ALU. Additionally, species evenness had a strong positive direct effect on ACS, but a strong negative direct effect of species diversity occurred. Finally, a strong positive indirect effect on ACS from canopy cover was found in CLU from 2009 to 2018. The findings can provide useful assessment indicators for managing peri-forests to improve forest carbon storage to speed up accomplishment of Sustainable Development Goals (SDGs).

Keywords Peri-urban · Island forest · Assessment method · Land use type · Aboveground carbon storage · Climate change

Introduction

With the societal demand for technology and energy has also risen accordingly, leading to many global problems across word. The emission of carbon dioxide is one of the most significant gases that causes the greenhouse effect. IPCC has shown that land use change and deforestation are the second largest contributor of carbon dioxide emission (Bordoloi et al. 2022). The goals of sustainable development (SDGs)

set out in 2015 the climate action (Goal 13) aimed at reducing greenhouse gases in the atmosphere (Jarvis 2020). The carbon storage of ecosystems is one of the important factors that affect climate change (Wang et al. 2021), and terrestrial ecosystems are the major sources of carbon storage (Pacala et al. 2001; Pan et al. 2011). In particular, forest ecosystem account for about 46% of the total entire terrestrial ecosystem carbon storage (Bo et al. 2006), which play an important role in reducing carbon emissions in the atmospheric environment (Xu et al. 2018). It is estimated that carbon sequestration by vegetation might offset 6–8% of China's future emissions (He et al. 2017).

Urban woody vegetation, its carbon storage can account for 14% of the carbon storage in the forest system (Godwin et al. 2015), means that their potential for carbon storage should be held in high regard. Urban woody vegetation consists primarily of trees and shrubs, which grow primarily in roadsides, residential areas and parks (Desjardins et al. 2014; Harris et al. 2018; Wang et al. 2022). There are also more

Yanyan Wei and Min Zhao were considered co-first authors.

✉ Jun Gao
gaojun@shnu.edu.cn

¹ School of Environmental and Geographical Sciences, Shanghai Normal University, Shanghai 200234, China

² Yangtze River Delta Urban Wetland Ecosystem National Field Scientific Observation and Research Station, Shanghai 200234, China

trees and shrubs growing on agroforestry systems and woodlands in the peri-urban areas. However, carbon storage of urban forests is spatially nonstationary. As urbanization has accelerated, the state of vegetation and the change in carbon storage in different land-use types have become increasingly common (Ge et al. 2008; He et al. 2019; Hutyra et al. 2011; Wang et al. 2021). Differences in tree management practices and increases in anthropogenic land use changes such as deforestation and agriculture, for example, have been shown to affect forest carbon storage in peri-urban (Godwin et al. 2015). A number of factors contribute to the influenced aboveground carbon storage (ACS) of urban forests, primarily attributed to the complex determinants (e.g., land development patterns and differing management regimes) that influence tree species diversity, tree density, canopy cover and variation in the size of individual trees (Chen et al. 2020; Dobbratz et al. 2022; Hutyra et al. 2011; Liu 2022; McNicol et al. 2018; Raciti et al. 2014; Ruiz-Jaen and Potvin 2011; Strohbach and Haase 2012a, b; Zhang et al. 2016). Currently, there is a great need to estimate the changes of woody vegetation condition and ACS in different land use types, especially for peri-urban areas with more agroforestry systems and woodland.

The biomass carbon pool is the component that plants store carbon through the process of photosynthesis, providing an indication of the storage of carbon above the ground in trees (Cannell 1999; Motaharfard et al. 2019). Allometric biomass equations are used to quantify urban tree biomass and carbon dynamics of different species and require information on the variation of tree height and diameter at breast height. These models have been used by some researchers to estimate biomass and carbon storage in different types of land use such as woodland, khat plantation, orchard and parkland (Cannell 1999; Motaharfard et al. 2019). There is uncertain that the ACS of different woody vegetation species are evaluated using allometric biomass equations in various land use types such as woodland, agriculture and construction land in chinese peri-urban areas. Moreover, few researchers have studied that the change in species diversity, canopy cover, species evenness and tree density impact on the change in ACS in different land-use types of peri-urban under the context of urbanization.

At present, there are some models such as the granger causality model and vector autoregression that can assess the causal relationship between two variables. However, the combined effect of multiple influencing factors cannot be quantified on ACS by these models. In comparison to others, structural equation modeling (SEM) can quantify the overall effect of multiple influencing factors on the target variables, and it can remove the influence from other variables to quantificate the impact of a variable (Yang et al. 2021). It recently has been applied in environmental science and

ecology (Yang et al. 2018; Zhu and Xia 2020). Therefore, the study conducted a permanent monitoring in Chongming Island of Shanghai, the purposes are to: (1) analyse temporal change in woody tree height at the plot scale, crown width and diameter at breast height, which relates to assessing ACS; (2) to examine species evenness, species diversity, canopy cover and tree density of the different land-use types from 2009 to 2018; (3) to estimate changes in ACS of woody urban vegetation in the ongoing monitoring of different land-use types; (4) to better understand the driving factors for ACS on major land-use types during 10-year period (2009–2018). I hypothesize that there are driving factors that influence ACS on the major land use types over the ten year period (2009–2018). The results of this study can be as a reference for regional land use policies, which can increase ACS and reduce greenhouse gases on different lands. This can be useful to improve forest management and establish climate action (Goal 13).

Study method and area

Study site

The latitude and longitude of Chongming Island is approximately 121°09'30" ~ 121°54'00" E and 31°27'00" ~ 31°51'15"N. Chongming Island formed as a result of the accumulation of running water. The annual temperature is 15.2 °C and rainfall is 1025 mm in Chongming Island Huang et al. (2008). Moreover, subtropical evergreen forests are the main vegetation types. In late 2009, a new bridge tunnel was built connecting Shanghai to Chongming Island and this decreased commuting time to 30-min (Zhao et al. 2013). In addition, Chongming Island relies on agriculture and is the main source of economy, which included maximum area of agricultural land uses. Besides, the forest and construction land uses (residential buildings, schools, transport, squares, etc.) account for a relatively large area of Chongming island (Fig. 1).

Methods for data collection

In 2018, the random plots were 178 circular 0.04 ha that originally established on Chongming Island in 2009 (Yang et al. 2018). Existing land uses, the center of the plot, and the canopy cover on each plot, was also visually estimated as was the direction and distance to each tree recorded during the 2009 and 2018 measurement times to reduce measurement errors again. The following specific measurements were collected for all woody on plots (Timilsina et al. 2014): the diameter at breast height of trees (DBH; 1.30m

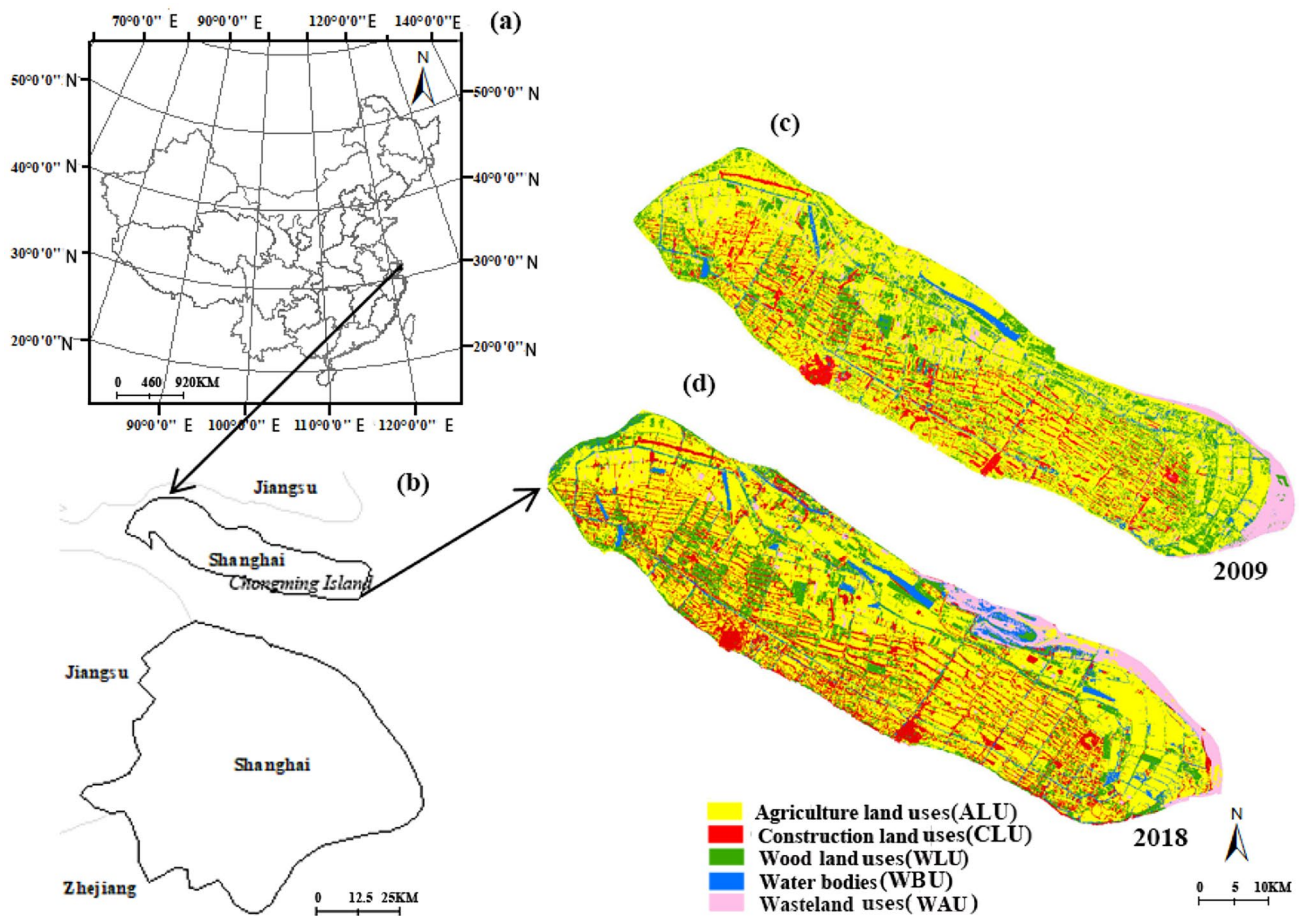


Fig. 1 The location of China (a), the Chongming Island location (b), land use types of Chongming Island in 2009 (c) and 2018 (d)

aboveground surface), species, total height, crown widths, and the number of individuals.

Overall, 70 percent of the plots were located on agricultural land uses (ALU), woodland (WLU) and construction land uses (CLU), and about 5% of the plots had changed in land use types during 2009 to 2018. There were 38 plots on ALU, 28 plots on WLU and 42 plots on CLU in 2009. In 2018, there were 40 plots on ALU, 34 plots on WLU, and 39 plots on CLU. Meanwhile, the other 30% of the plots were mainly distributed on water bodies and wasteland uses. The study mainly estimated the changes in ACS from 2009 to 2018 in permanent monitoring sites where there were no change in land use type (Fig. 2).

Forest structure and composition analysis method

The four indexes of forest structure and composition were calculated by Eqs. 1–4.

$$PD_i = N_i/S_i \tag{1}$$

$$P_m = \frac{n_m}{N} \tag{2}$$

$$H = - \sum_{m=1}^s p_m \ln P_m \tag{3}$$

$$E = H / \ln S \tag{4}$$

where PD_i , N_i , S_i , H , E , S , n , N , P_m represents tree density (tree/ha), number of tree, area of the i plot (0.04 ha), species diversity, species evenness, number of species, numbers of m species, numbers of all species and the relative dominance of m species, respectively.

Carbon storage estimation method

For tree and shrub carbon storage, we used biomass equations which are then multiplied by the carbon coefficient of 0.5 (Yao et al. 2017). For tree and shrub biomass estimation are from published of Zhao and Zhou (2006). For estimation

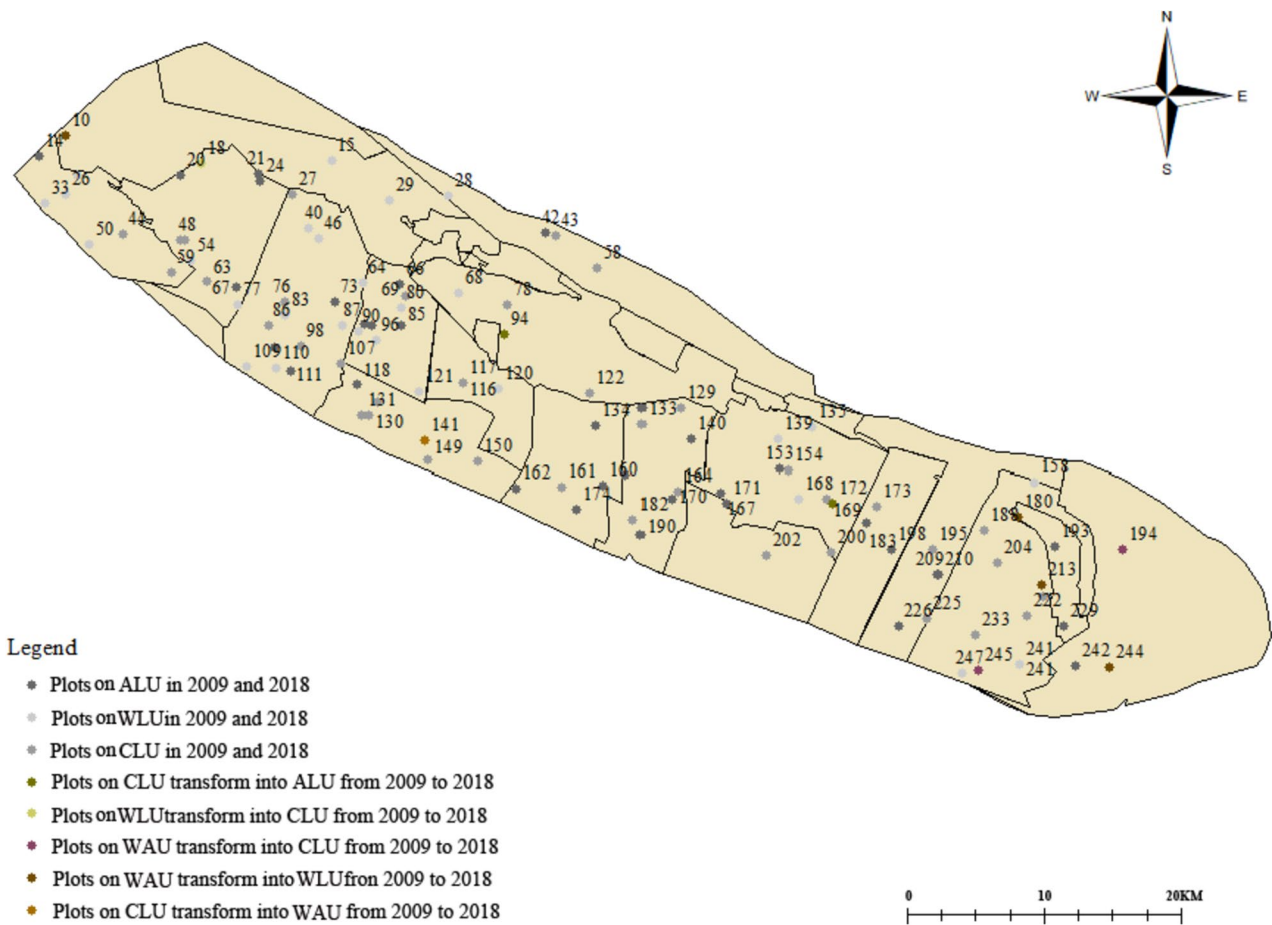


Fig. 2 Distribution of field survey plots in Chongming Island, China

method of ACS in various land types, which shown Eqs. 5 and 6:

$$ZB_i = GB_i + QB_i \tag{5}$$

$$Cc_i = \frac{ZB_i \cdot Cc}{S_i} \tag{6}$$

where ZB_i , GB_i , QB_i , Cc_i , Cc , S_i represents biomass of woody vegetation (Mg), biomass of all shrubs, biomass (Mg) of all trees, the carbon storage (Mg C/ha) in the i plot, the conversion coefficient (0.5) and the area of i plot (0.04ha).

Structural equation modeling

The structural equation model (SEM) analysis method was used to analyze the driving factors behind carbon storage change in the three main land use types. Structural equation model is a method that accounts for the causal influence of multiple variables on a dependent variable. The relationship between each correlation variable can be accurately calculated by structural equation modelling.

Accordingly, all sample data were imported into SPSS for validity verification using the KMO and Bartlett sphericity test. The value of Kaiser–Meyer–Olkin (KMO) was > 0.5 , the bartlett sphericity test was at the level of 0.001, and the data validity met the requirements before constructing the structural equation model (Dalkilic et al. 2021). In addition, selected relevant variables establish a preset model by Mplus8.3 basis on the correlation between variables through statistical analysis and theoretical knowledge. The Model are based on Eqs. 7–9:

$$y_1 = \alpha_1 + \gamma_{11}x_1 + \xi_1 \tag{7}$$

$$y_2 = \alpha_2 + \beta_{21}y_1 + \gamma_{21}x_1 + \xi_2 \tag{8}$$

$$y_3 = \alpha_3 + \beta_{32}y_2 + \gamma_{31}x_1 + \xi_3 \tag{9}$$

where x_1 is independent variable, and y_1, y_2, y_3 are three dependent variables. γ (γ_{11}, γ_{21} and γ_{31}) represent pairs of variables x influence of the variable y , β (β_{21} and β_{32}) denotes the influence of the variable y , ξ Residuals of response variables.

Table 1 The maximum, mean and minimum values of tree dimensions

	Land use types	n	Max		Mean ± SE		Min	
			2009	2018	2009	2018	2009	2018
DBH (cm)	ALU	38	35.0	30.3	10.6 ± 1.12	22.1 ± 1.08	1.90	3.18
	WLU	28	22.4	52.6	7.90 ± 0.98	15.3 ± 1.23	4.10	0.48
	CLU	39	45.5	57.3	18.4 ± 2.11	20.8 ± 1.73	4.50	3.18
Tree height (m)	ALU	38	14.5	18.0	5.80 ± 0.21	5.60 ± 0.39	2.00	1.50
	WLU	28	23.0	25.0	5.40 ± 0.17	6.30 ± 0.42	1.70	1.00
	CLU	39	18.0	18.0	8.95 ± 0.32	8.25 ± 0.56	2.80	2.30
Crown widths (m)	ALU	38	7.90	6.5	3.30 ± 1.01	2.90 ± 1.33	1.00	0.50
	WLU	28	13.0	12.9	2.50 ± 0.57	4.10 ± 1.22	0.80	0.30
	CLU	39	11.7	9.0	3.90 ± 0.81	3.70 ± 0.94	0.90	0.35

Results

In 2018, a total of 64 woody species were recorded. There were mainly dominated by tree woody species in ALU and WLU, while CLU had a larger number of shrub woody species. The analysis of the top 5 tree and shrub species showed that according to the number. The top 2 tree species were *Cinnamomum camphora* (L.) Presl and *Metasequoia glyptostroboides* Hu & W.C.Cheng in the ALU, WLU and CLU. *Melia azedarach* Linn was replaced by *Ligustrum lucidum* in ALU, deciduous plants *Diospyros Kaki* L.f and *Robinia pseudoacacia* Linn were replaced by evergreen plants *Ligustrum lucidum* and *Osmanthus sp* in CLU, but the top 5 tree species in woodland were not changing from 2009 to 2018. *Osmanthus sp*, *Photinia serrulata* Lindl and *Buxus sinica* var. *parvifolia* M. Cheng were the most common shrub species in 2009 and 2018. The top 5 shrub species also included *Citrus reticulata* and *Prunus persica* in ALU, WLU and CLU in 2009, but not in 2018. In 2018, the top 1 shrub species were *Photinia serrulata* Lindl in ALU and WLU, while the numbers of *Osmanthus sp* was the highest in CLU.

Tree and shrub dimensions were measured and calculated, and the maximum, mean and minimum values were presented in Tables 1 and 2. In 2009 and 2018, the mean diameter at breast height (DBH) exhibited the following: CLU > ALU > WLU. Notably, the mean DBH of

WLU remained the lowest in 2009 and 2018. Over the study period, a significant increase in DBH was observed for trees in ALU, WLU and CLU, with growth rates of 52.04%, 48.37%, and 11.31%, respectively. It is worth highlighting that there were the least pronounced increase of DBH in CLU. In addition, there were no significant change in height and crown width of trees and shrubs in ALU, WLU and CLU from 2009 to 2018, which may be related to the regular artificial pruning.

The dynamic of vegetation index in main land use types

In Fig. 3, the forest structure and composition in ALU, WLU and CLU had notable changes and differences between 2009 and 2018. In 2018, ALU, WLU and CLU had higher species evenness, higher species diversity, higher canopy cover and higher tree density than 2009. Mean tree densities and tree canopies increased by over 40% in ALU (Fig. 3(a, c)). Meanwhile, mean canopy cover also had a significant increase, but mean tree density did not change significantly in WLU and CLU. Even so, the average tree density and canopy cover in WLU were still highest in 2009 and 2018. The average species evenness and species diversity had a significant increase in WLU but a slight increase in ALU and CLU from 2009 to 2018 (Fig. 3b, d).

In addition, the statistical significance analysis of forest structure and composition, a scientific way of explaining

Table 2 The maximum, mean and minimum values of shrub dimensions

	Land use types	n	Max		Mean ± SE		Min	
			2009	2018	2009	2018	2009	2018
Tree height (m)	ALU	38	8.00	5.80	2.12 ± 0.31	3.20 ± 0.20	1.20	1.30
	WLU	28	9.80	12.0	4.00 ± 0.54	3.10 ± 0.36	1.50	0.50
	CLU	39	6.80	6.50	2.02 ± 1.13	2.10 ± 0.95	0.80	0.50
Crown widths (m)	ALU	38	5.00	3.75	2.40 ± 0.18	2.30 ± 0.24	0.83	0.90
	WLU	28	6.50	7.44	3.20 ± 0.37	2.90 ± 0.19	0.70	0.25
	CLU	39	5.25	7.75	1.70 ± 0.14	2.50 ± 0.62	0.50	0.45

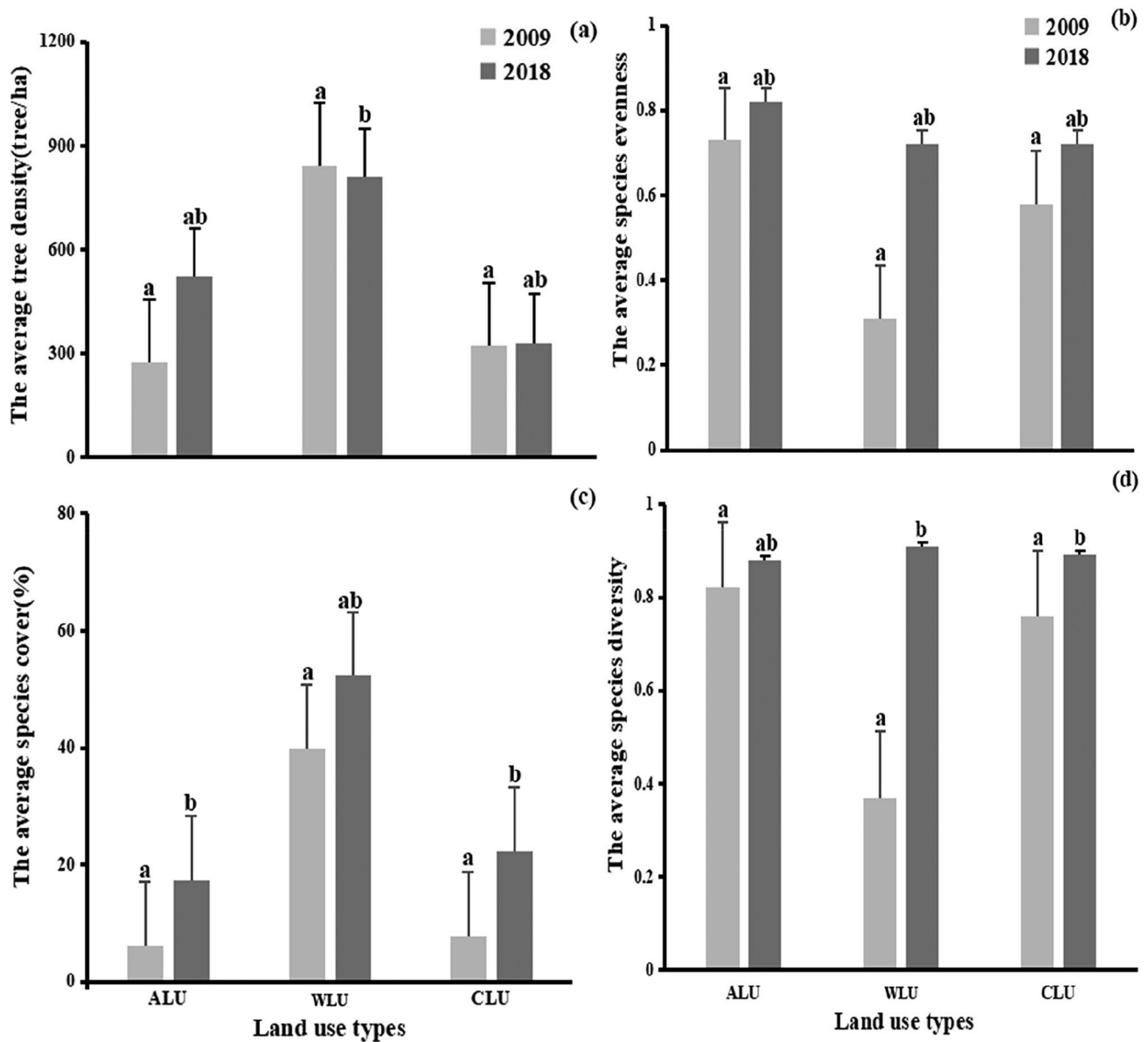


Fig. 3 The average tree density (a), the species evenness (b), the canopy cover (c), the species diversity (d) on agricultural land uses (ALU), woodland (WLU) and construction land uses (CLU) from

2009 to 2018. 'a and ab between group' represents non-significant difference, 'a and b between group' arrows represent significant difference

the difference between two years of data. The results shown that the difference of average species evenness in ALU, WLU and CLU was not significant in 2009 and 2018. When the difference in canopy cover was not significant with approximately 50% in WLU in 2009 and 2018, there was a significant difference in tree density and species diversity. In ALU, the results were completely opposite of the difference of WLU's in 2009 and 2018. Moreover, it were significant that the difference of canopy cover and species diversity, but difference of tree density were not significant on CLU in 2009 and 2018.

The dynamic of ACS in the main land use types

Table 3 illustrates the differences between ACS the difference land use types in various years. Overall, the ACS in 2018 was higher than in 2009 in ALU, WLU and CLU. Meanwhile, the tree ACS was higher than shrub ACS in different land use types in 2009 and 2018. The average of ACS in each sample point increased 2.07 MgC/ha in ALU, 9.89 MgC/ha in WLU, 4.06 MgC/ha in CLU. The majority of change in ACS was from tree species, while a small amount came from shrub species (Fig. 4). The highest

Table 3 ACS (Mg/ha) of each sample point (0.04 ha) in main land use types

Land use types	n	Max		Mean		Min	
		2009	2018	2009	2018	2009	2018
ALU	38	11.52	21.79	1.90	3.97	0.11	0.12
WLU	28	43.32	74.81	8.63	18.52	2.94	2.77
CLU	39	28.55	55.31	3.38	7.44	0.07	0.18

amount of change in total ACS was from *Cinnamomum camphora* (L.) Presl followed by *Metasequoia glyptostroboides* Hu & W.C.Cheng among the five most common woody species in the difference land use types from 2009 to 2018, and the order of change was WLU > CLU > ALU.

The main driving factors of ACS across land use types

Design SEM

The changes in species evenness (CSE), species diversity (CSD), canopy cover (CCC), and tree density (CVD) from 2009 to 2018 were used to reflect the impacts of the dynamic of forest structure on the change in ACS (CACS) in our study area. Using the factor analysis method of SPSS, the change in CACS, CSE, CSD, CCC and CVD in ALU, WLU and CLU from 2009 to 2018 were tested by KMO and Bartlett sphericity test, and indicating that all data were normally distributed. The Pearson correlation analysis demonstrated

that tree density had the greatest impact on ACS, followed by species diversity. ACS was less affected by evenness of species and canopy cover (Fig. 5). Unfortunately, it was difficult for Pearson coefficients to represent the relationship between individual input variables and the output variable in an accurate way due to complex non-linear relationships among multiple independent and dependent variables (Jiang et al. 2022). Structural equation modelling (SEM) offered a suitable method for assessing non-linear correlations. Therefore, based on the Pearson correlations between CACS, CSE, CSD, CCC and CVD, as well as prior knowledge, to propose a preset model that can characterize the causal relationship between the measured variables. Then we combined the results of correlation analysis to model the driving factors affecting changes in ACS in ALU, WLU and CLU (Fig. 6).

The impact driving forces of ACS

The SEM accounted for changes in tree density and this had a strong positive direct effect on ACS ($P \leq 0.01$), particularly

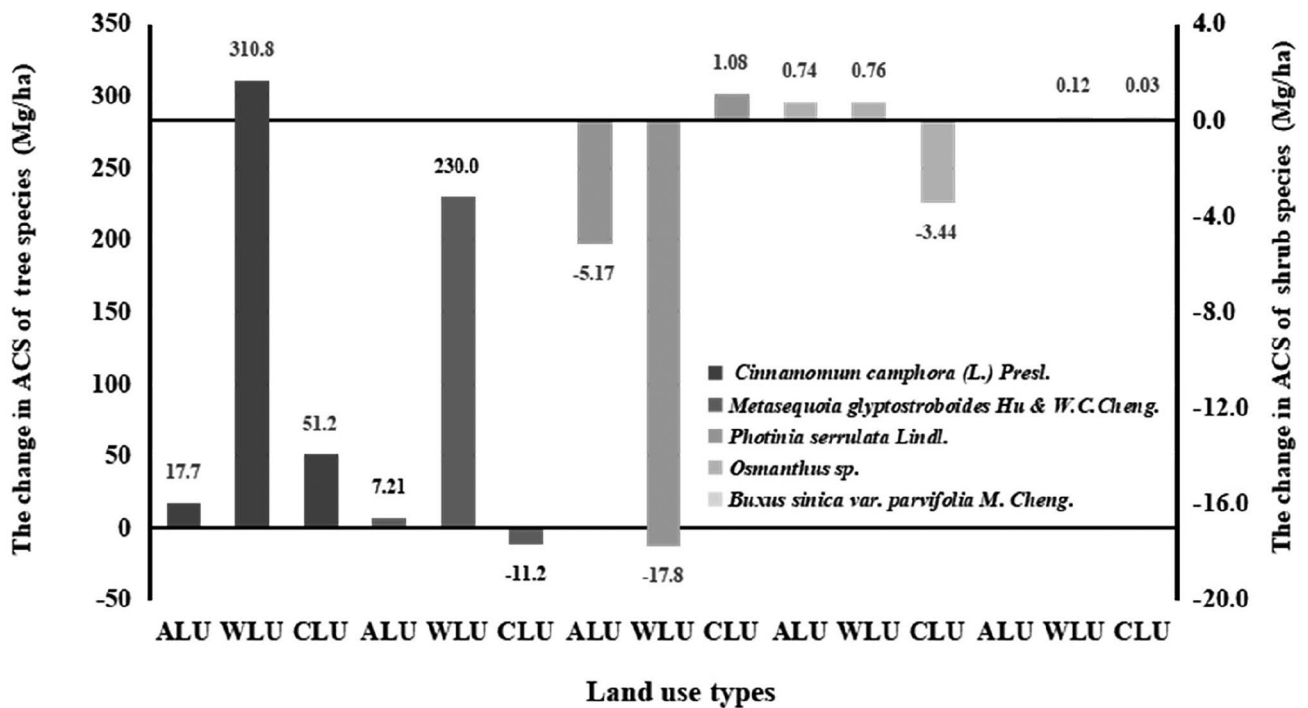
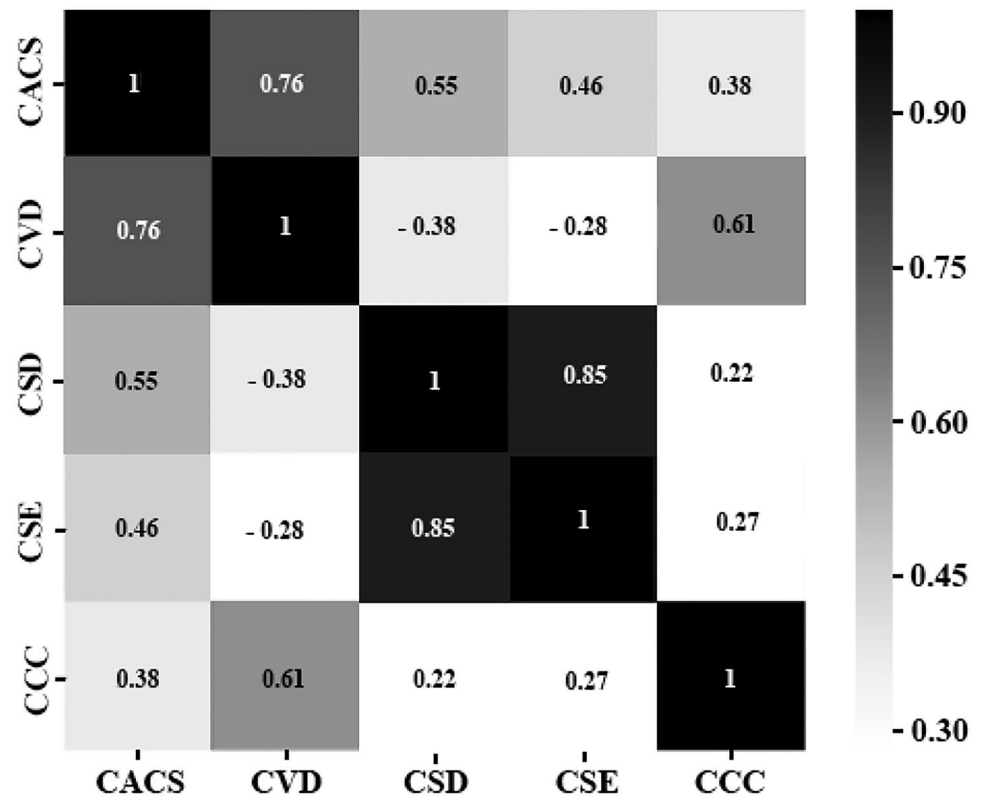


Fig. 4 The majority of change in ACS of main woody species

Fig. 5 Pearson correlation analysis



in WLU. In ALU, canopy cover had the strongest positive direct effect on ACS. However non-significant direct effects were observed with changes in species diversity ($P > 0.05$), species evenness ($P > 0.05$) and canopy cover ($P > 0.05$) in WLU and CLU. In addition, the change in species evenness and the change in species diversity had non-significant direct effects on the change in canopy cover and tree density, the change in canopy cover had non-significant direct effects on the change in tree density in ALU, WLU and CLU. The change in species evenness, species diversity, canopy cover and tree density had also non-significant indirect effects on ACS in ALU and WLU. Moreover, the change in species

evenness and species diversity had a strong positive direct effect on ACS ($P \leq 0.01$), the change in canopy cover had a strong positive indirect effect on ACS ($P \leq 0.01$) in CLU from 2009 to 2018 (Fig. 7).

Discussion

Woody vegetation characterization

Recorded a total of 64 woody species at the study site, and the invariable, dominant woody species encountered primarily *Cinnamomum camphora* (L.) Presl, *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Osmanthus* sp, *Buxus sinica* var. *parvifolia* M. Cheng and *Photinia serrulata* Lindl in 2009 and 2018. The results is similar to Wang Zhe’s in 2013 (Wang et al. 2013). The number of *Citrus reticulata* and *Prunus persica* declined dramatically from 2009 to 2018 on the five dominant species at the top of the hierarchy. It seems that the result appears to be the result of policies in different times. With the completion of the Yangtze River Bridge in 2009, which dramatically altered the inconvenient urban transportation pattern of Chongming Island and Shanghai’s downtown area. However, this might lead to many young people who live in Chongming to make a living to the city center rather than planting fruit trees on the island, which was also one of the main reasons why

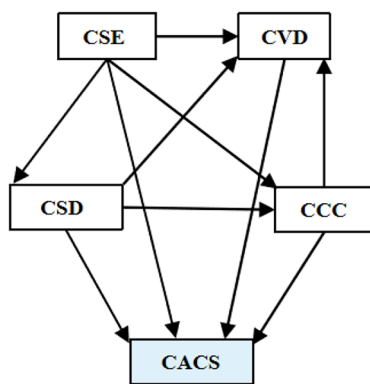


Fig. 6 The preset SEM

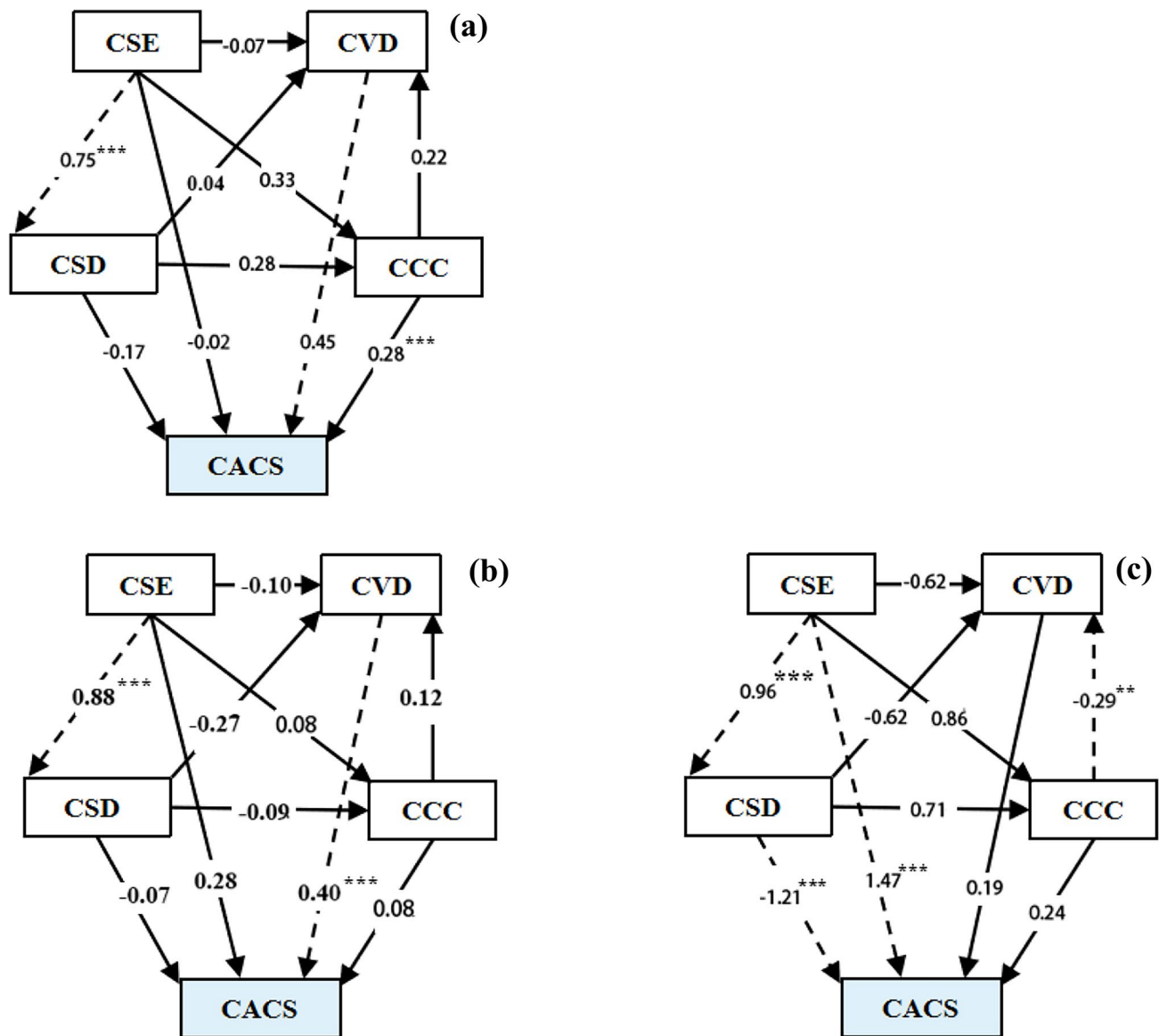


Fig. 7 The results of SEM on ALU (a), WLU (b), CLU (c). Solid represents non-significant paths. Dashed represents significant paths. *** represents strong significance ($P < 0.01$), ** represents significance ($0.01 \leq P \leq 0.05$). Establish the structural equation through MPLUS8.3. The chi-square value ($X^2/df=0.0$). The informal fitting index ($TLI=1.0$).

The comparative fitting index ($CFI=1.0$) of the structural equation constructed by each driving force of changing in carbon storage of vegetation are all within the range of judgment values on ALU, WLU and CLU which indicates that the goodness of fit of the model is good

the field survey has shown that there are more elderly people living in Chongming in 2018. Compared to 2009, more evergreen plants such as *Ligustrum lucidum* were increased in 2018, especially in the construction land (CLU). The CLU mainly include residential buildings, schools, transport lands, squares, etc., and residential buildings and transport lands account for most of CLU. According to Amjad Khabaz's research results, green plants led to improvements of up to 89% on the thermal insulation performance of roofs (Khabaz 2018). Meanwhile, evergreen plants can purify the air, which is beneficial to human health and improve the

living environment of cities (Su et al. 2019). These may be two important reasons for the increase of evergreen plants in CLU from 2009 to 2018.

A scientific way of explaining the difference of species evenness, species diversity, canopy cover and tree density in ALU, WLU and CLU between 2009 and 2018. The average of species evenness revealed non-significant increased in ALU, WLU and CLU. There were mainly crops in ALU, the woody species were mostly *Cinnamomum camphora* (L.) Presl and *Metasequoia glyptostroboides* Hu & W.C.Cheng in 2009 and 2018. The increased of tree density and

species diversity were also non-significant, but a significant increase in canopy cover of ALU. Celia García-Feced's study also found that the vegetation cover of some agricultural lands shown an increasing trend, and the increased of vegetation cover contributes to ecosystem services such as pest control and water quality control (García-Feced et al. 2015). In WLU, there were increase many species such as *Celtis sinensis Pers*, *Magnolia officinalis*, *Viburnum odoratissimum Ker -Gawl* and *Elm tree* in 2018, which was what one causes the tree density and species diversity were significant increased from 2009 and 2018. Moreover, the more city dwellers must be confronted many environmental problems such as urban heat island and air pollution with the current rapid of urbanization (He et al. 2018; Leite et al. 2012; Liu and Shen 2014). Many researchs clearly shows the vital of trees and shrubs in mitigating these problems (Chen et al. 2020; Klobucar et al. 2021). Meanwhile, evergreen vegetation was more conducive to reducing CO₂ in the atmosphere because net photosynthesis on a leaf area basis of evergreen vegetation was higher than deciduous vegetation (DeLucia and Schlesinger 1995). Therefore, the species diversity shown significant increased in CLU from 2009 to 2018. In particular, there was most clearly seen with increasing evergreen species such as *Ligustrum lucidum*, *Osmanthus sp* in CLU. In addition, the canopy cover also shown significant increased in CLU, which was the same result as ALU. The result seems be related to policies of Shanghai. In 2010, shanghai took advantage of the opportunity presented by World Expo to improve its green space network system, and manage the green space under the law (Wei et al. 2021), According to the Chongming Ecological Island Construction Outline released in the same year, the forest cover increased to 28 percent in Chongming by the year 2020. These measures made the canopy cover suitable for increasing.

The dynamic of ACS

In the study, the carbon storage of each woody vegetation was calculated by biomass equations. The result showed that mean ACS of ALU, WLU, and CLU in 2018 was higher than in 2009, Guo Rul analyzed the change of carbon storage in Chongming Island from 2005 to 2013, the result shown that urbanization may lead to the increase of carbon emissions and the degradation of regional ecological services. The land use changes can impact on ecosystem carbon balance because of urbanization (Wang et al. 2021), and directly affect the carbon storage capacity of vegetation (Escobedo et al. 2010; Nowak and Crane 2002; Zhao et al. 2010). Only about 5% of the plots had changed land use types according to the field investigation in Chongming Island from 2009 to 2018, and which effect on ACS was expected to be little. Additionally, the structure and composition of forests can determine biomass dynamics directly, but also indirectly,

through regulation of trait diversity and composition in a community (Cai et al. 2020). Therefore, the increased in ACS was mainly influenced by the changes in vegetation characteristics.

The order of changing in ACS was WLU > CLU > ALU, which was similar to the result of other researchers (Gebre et al. 2019; Rajput et al. 2017; Thompson et al. 2016). Mingdong found the carbon storage of trees was significantly higher than shrubs, and similar result were also seen with respect to Sundarapandian's research (Ma et al. 2009). In the study, one of the reasons that ACS in WLU increased the most may be that where contains the greatest number of trees. Besides, the ACS of the top five dominant woody species in WLU increased by more than a factor of two compared to those in ALU and CLU. In CLU, woody vegetation are indeed improving air quality, as evidenced by increases in ACS. In the ecosystem, evergreen species contributed more to carbon storage than deciduous species (Tamilselvan et al. 2021). The increasing of evergreen species might be one of the important reasons that ACS in CLU. In the present study, *Cinnamomum camphora (L.) Presl*, *Metasequoia glyptostroboides Hu & W.C.Cheng*, *Ligustrum lucidum*, *Osmanthus sp*, *Photinia serrulata Lindl*, and *Buxus sinica var. parvifolia M. Cheng* were the important contributor of ACS. Conserving these species will therefore have important effect on carbon storage. In particular, *Cinnamomum camphora (L.) Presl*, and *Metasequoia glyptostroboides Hu & W.C.Cheng* were shown significant role in influencing the change in ACS.

The main driving factors of ACS

To the best of our knowledge, it is essential to analyze the multivariate relationships between changes in ACS and changes in vegetation characteristics in difference land use types. The SEM showed that the change in tree density had the strongest positive direct effect on ACS in WLU. Higher tree density is one of the important reasons for stronger photosynthesis of vegetation, and therefore, the greater ACS. Other researchers had also shown that vegetation density had a positive effect on ACS through structural equations (O Donoghue and Shackleton 2013). Generally species diversity and canopy cover were considered as component of forest structure. In natural forests, species diversity and canopy cover could promote ACS (Ali et al. 2016; Sunde et al. 2020; Wang et al. 2011). In ALU, canopy cover had the strongest positive direct effect on ACS and might be influenced by a significant increase of canopy cover from 2009 to 2018. The study showed that the change in ACS was directly effected by the change in species diversity and species evenness on CLU. In the meantime, the change in canopy cover had a strong indirect effect on ACS on CLU land from 2009 to 2018. Ali et al. showed that species diversity were

significant direct effects on aboveground biomass through SEM by testing the direct and indirect effects of species diversity on aboveground biomass (Ali and Mattsson 2017), which was similar to the study. Moreover, many researchers demonstrate that changes in vegetation cover may be a strong indicator of changes in carbon storage (Dănescu et al. 2016; Fernandes et al. 2015).

ACS would be expected to increase substantially with species diversity (Zhang et al. 2012), but the result of the study were opposite in CLU. In addition, the change factors of ACS were different on different land types in the study. There was mainly based on crop plants in ALU, and the forest structure was more homogenous comprised mainly of metasequoia and camphor trees in ALU and WLU. So, the impact of species evenness and species diversity changes on ACS were less in ALU and WLU. However, Cardinale shown that the cause of species diversity effects on the ACS may be the highly productive species dominate the processes in diverse communities in homegarden agroforestry systems (Cardinale et al. 2011). Thus, the selective addition of woody species may contribute to an increase in ACS in ALU. In CLU, there are different forest structures and compositions because of various functions which including transportation and residential. Therefore, the ACS on CLU was affected by varieties of forest structures and compositions.

There were some limitations in the study. The increasing species diversity can lead to reduced biomass partitioning in the belowground portion and aboveground biomass production can be increased (Cardinale et al. 2011). Meanwhile, findings show that there is a correlation between ACS and belowground carbon storage due to a positive interaction between shoot and root competition (Li et al. 2019). However, it is not clear that the changes in underground carbon storage impact on changes in ACS. So, future research is needed to better understand the relationship between underground carbon storage and ACS.

Conclusion

Ecological management and restoration projects can change forest structure and composition. We investigated the change in ACS on ALU, WLU and CLU from 2009 to 2018. Meanwhile, we analyzed the effects of changes in forest structure and composition on ACS by SEM on ALU, WLU and CLU from 2009 to 2018. According to the study, the ACS of ALU, WLU and CLU in 2018 was higher than 2009, and the ACS increased more significantly in WLU than on ALU and CLU. The change in ACS was influenced by a combination of vegetation management, woody species, species evenness, species diversity, canopy cover, and tree density.

The current findings can be beneficial to inform how to reduce greenhouse gases in the atmosphere. It suggested

that tree planting can increase the ACS on different land use types. Tree density can be increased in WLU, and the increased woody species and canopy cover may contribute to an increase in ACS in ALU. Tree type or forest structure should be selected according to the function of land type on construction land uses. For example, plantings can be mainly ornamental vegetation around schools and resident. In other types of construction land with high carbon dioxide emissions such as factories and traffic areas with many vehicles, it is suggested to plant more evergreen trees such as camphor tree to offset emissions. The study quantified the indirect impact of eco-island construction on forest structure and composition, and the relationship between the change in forest structure and composition and the change in ACS, which could provide a reference for ecological management to accomplish the climate action (Goal 13).

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Declarations

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