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Accuracy of space-for-time substitution for vegetation state prediction following shrub restoration

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Abstract

Aims:
Space-for-time substitution (SFT) is often used for vegetation status estimation during the recovery process of deserts. However, the evaluated accuracy of SFT remains uncertain. An eight-year located observation was used to assess the validity of SFT for vegetation state prediction.

Methods:
This study analyzed a chronosequence of *Caragana microphylla* Lam. plantings using the located observation method to test the accuracy of SFT for vegetation state prediction in the mobile sand dunes of the Horqin Sandy Land in northeastern China from July 2005 to June 2013.

Important Findings:
According to SFT, simple vegetation parameters (density, coverage and biomass) were found to be unstable, while sophisticated vegetation parameters (species diversity and evenness) were relatively stable across the experimental treatments during the study period. Conversely, both the simple and sophisticated parameters were found to be relatively stable when tested using the located observation method. Furthermore, most simple vegetation parameters slightly increased, while sophisticated parameters slightly decreased after eight years of field observations. Thus, long-term restoration management facilitated improvements in the simple parameters, but may have adversely impacted the sophisticated parameters in the post-restoration community. Our results suggest that sophisticated vegetation parameter states can be predicted by SFT, while simple vegetation parameter states are not well predicted by SFT. In conclusion, located observations or other effective evaluation methods must be employed to offset the deficiency of the SFT method for the prediction of vegetation parameters.

Keywords: community structure, desertification, location observation, restoration, stability

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INTRODUCTION

Space-for-time substitution (SFT) uses sites of different stages and ages of succession at separate locations to infer vegetation succession characteristics (Hasselquist *et al.* 2015). Assessing vegetation characteristic states with SFT is commonly used for restoration studies (Liu *et al.* 2009, 2013). However, the prediction accuracy of SFT may be influenced by variations in environmental conditions (e.g. rainfall, groundwater, salinity) and previous population fluctuations (Foster and Tilman 2000; Whiles and Charlton 2006). Thus, the actual vegetation characteristic states are difficult to predict in detail with SFT, especially in highly variable environments (Foster and Tilman 2000; Pickett *et al.* 2001). Despite these shortcomings, few studies have confirmed the validity of SFT for predicting vegetation parameters by using located observation across the same sites following a succession period.

Moving sand dunes, extreme deterioration of the soil environment, hamper plant invasion and survival (Durán and

Herrmann 2006; Li *et al.* 2013; Miao *et al.* 2015). The planting of shrubs in the center of a straw checkerboard (PSC) pattern can facilitate the redevelopment of vegetation, which is beyond the actual restoration area within the bounds of the natural vegetation areas of sand dunes (Akiyama and Kawamura 2007; Cao *et al.* 2008; Liu *et al.* 2013). Large areas of PSC sites have been established and conserved in semi-arid desert regions. However, since a practical and effective evaluation method is lacking, the degree of reconstruction and conservation has not been well assessed (Wortley *et al.* 2013). The goal of ecological restoration is to recover or re-establish ecosystems such that they approach the natural ecosystem state and are maintained at relatively stable states (Hobbs and Norton 1996). Assessing changes in vegetation parameters over time is one objective of vegetation restoration in deserts (Ruiz-Jaén and Aide 2005; Ives and Carpenter 2007).

Numerous assessments of post-restoration vegetation characteristics have been conducted, and most use space-for-time substitution (SFT) alone as no other methods can easily predict long-term variations in vegetation and community states with contemporary community characteristics (Liu *et al.* 2009, 2013). However, the use of SFT alone provides inadequate results (Johnson and Miyanishi 2008; Ra´cz *et al.* 2013), and better methods are required to address those aspects not addressed by SFT. As initial environmental conditions and environmental variability can determine future vegetation (Jentsch *et al.* 2011; Giuliani *et al.* 2014; Hallett *et al.* 2014), actual post-restoration vegetation characteristics are needed to test the accuracy and offset the shortcomings of the SFT method. An eight-year field observational experiment was thus conducted to compare the SFT prediction result using a chronosequence of PSC sites in the Horqin sandy land, northeastern China. We sought to assess the accuracy of SFT for vegetation restoration assessment during sand dune stabilization using PSC and provide an experimental basis for restoration area management and utilization. We investigated vegetation parameters predicted with SFT in the PSC treatments and compared these data to eight years of field observations. The objective of this study was to assess the accuracy of SFT in predicting vegetation parameter states during restoration to confirm which parameters could be best predicted with SFT and determines which parameters require the addition of located observation or other effective methods to produce reliable results.

MATERIAL AND METHODS

Study site description

The study was conducted at the Wulanaodu Station of Desertification Research (43°02′N, 119°39′E, 480 m a.s.l.), Chinese Academy of Sciences, northeastern China. This area comprises a semiarid continental climate. Long-term (1987–2012) climatic data indicate a mean annual temperature of 7.3 (± 0.7) °C, ranging from −11.5 (± 0.5)°C in January to 23.7 (± 0.2)°C in July. In addition, the annual accumulated temperature is 3435.0 (± 24.0)°C (≥10°C) and mean annual precipitation is 303.7 (± 20.4) mm, ranging from 1.7 (± 0.5) mm in January to 91.9 (± 9.1) mm in July. The mean annual wind velocity is 4.4 $m \cdot s^{-1}$, and the dominant wind direction is northwest (March to May) and southwest (June to September). Soils are cambic arenosols that are sandy in texture and loose in structure, and soil moisture content (measured at a depth of 0–20 cm) ranges from 3.17% (dry season) to 3.33% (rainy season). Thus, the soils of the study sites are highly susceptible to wind erosion (Cao *et al.* 2011). The area has been subjected to overgrazing, and moving sand dunes are a common feature of the environment where the vegetation coverage is less than 5% on the dunes (Miao *et al.* 2015). The dunes are severely degraded (Li *et al.* 2003) and are primarily invaded by pioneering plant species (e.g. *Agriophyllum squarrosum*, *Artemisia wudanica* and *Setaria viridis*). The implementation of PSC has previously been found to be useful for stabilizing moving sand dunes in order to combat desertification and restore degraded lands (Miao *et al.* 2015).

Experiment design and sampling

To test the accuracy of SFT in predicting the of post-restoration vegetation stste, we examined the restoration state of a chronosequence of *Caragana microphylla* Lam. (little leaf peashrub) community using located observation in the sand dunes. As a pioneer species for vegetation reconstruction, *C. microphylla* has been widely used to stabilize moving sand dunes in the Horqin sandy land (Zhang *et al.* 2006; Zhao *et al.* 2007; Cao *et al.* 2008). The straw checkerboard prevents sand dune movement and provides a relatively stable microenvironment that facilitates plant colonization during the initial stages of restoration (approximately four to five years), after which it decays (Li *et al.* 2006). In order to establish a straw checkerboard (1 m × 1 m) on the dunes, parallel and vertical lines were drawn towards the prevailing wind erosion direction, and then straw (0.5 kg per prolonged meter) was perpendicularly distributed on the lines. Straw stems were inserted to a depth of approximately 15 cm and were exposed approximately 20–25 cm above the soil surface (Qiu *et al.* 2004; Zhang *et al.* 2004). Thereafter, one *C. microphylla* plant (40 cm) was planted in the center of each square of the straw checkerboard. Prior to artificial restoration, the free grazing intensity had been 4.5–5.0 sheep ha^{-1} since the mid-1950s (Miao *et al.* 2015). At the restoration sites, livestock grazing and other forms of land utilization were prohibited following the initiation of the experiment. The first treatment commenced in 1987.

By 2005, there were large areas of different-time-level PSC sites distributed in the Wulanaodu region. In late July 2005, four representative PSC treatment levels, encompassing large areas, were selected for vegetation recovery evaluation using SFT. We used PSC sites from the years 2000, 1995 and 1987 and a natural *C. microphylla* community treatment level (marked as T_{2000}, T_{1995}, T_{1987} and CK). Three representative sand dunes (as three replicates) in each PSC level were selected as experimental sites. Each sand dune was 300–400 m in length, 50–60 m in width and 5–10 m in height above the interdunal depressions. A representative plot of each sand dune (20 m × 30 m in area) was selected for investigation. All plots were at least 10 m from the sand dune edge to avoid possible edge effects. To test the accuracy and significance of SFT for predicting vegetation recovery, the experiment was conducted in the same plots in late July 2013. For comparison with the 2005 investigations, the 2000, 1995 and 1987 PSCs and natural *C. microphylla* community levels were marked as T'_{2000}, T'_{1995} T'_{1987} and CK′ in 2013. At each selected plot, five quadrants (2 m × 2 m) were chosen at random locations and orientations. The mean height, crown diameter and shoot number of *C. microphylla* was recorded (Table 1). Species richness and plant density were recorded by counting, and vegetation coverage was recorded using a grid-based estimate method in each plot quadrant. In the density investigations, a ramet for a shrub or an annual herb was regarded as an individual plant, while a cluster for a perennial herb was regarded as an individual plant. To avoid ecosystem destruction, only one representative 1 m × 1 m quadrant was harvested within each 2 m × 2 m quadrant to measure the fresh weight of the aboveground vegetation. The species were divided into six life forms: annual-biennial herbs (ABH), annual herbs (AH), perennial herbs (PH), shrubs (S), semi-shrubs (SS) and trees (T). The Siberian elm (*Ulmus pumila* Lam.) exhibited a shrub-like growth form in the study area, growing less than 10 cm in height; therefore, it was categorized as a shrub in the data analysis.

Data analysis

Hill's diversity number, which is the "effective number of species" or "species equivalents", was chosen to calculate true diversity indices (Hill 1973; Jost 2006). Hill's diverse number was calculated as follows:

Table 1 Characteristics of *Caragana microphylla* at four treatment levels in 2005 and 2013

PSC levels	Mean height (cm)	Crown diameter (cm × cm)	Shoot number (N)
T_{2000}	73.9 ± 3.34	92.1 × 82.8	10.8 ± 0.78
T_{1995}	71.0 ± 3.76	97.2 × 85.1	12.0 ± 1.09
T_{1987}	103.3 ± 7.47	100.4 × 104.2	16.3 ± 2.41
CK	103.3 ± 7.15	313.3 × 330.0	99.5 ± 5.77
T'_{2000}	130.5 ± 9.61	162.7 × 160.7	21.5 ± 1.49
T'_{1995}	116.1 ± 4.97	141.9 × 152.5	16.5 ± 1.42
T'_{1987}	103.5 ± 6.10	124.5 × 127.9	15.7 ± 1.66
CK′	143.4 ± 7.01	189.2 × 174.2	36.2 ± 5.54

PSC, Shrub planting in the center of a straw checkerboard; T_{2000}, T_{1995}, T_{1987} and CK, 2000, 1995 and 1987 PSC, and natural *C. microphylla* community treatment levels in 2005; T'_{2000}, T'_{1995}, T'_{1987}, and CK′, 2000, 1995 and 1987 PSC, and natural *C. microphylla* community treatment levels in 2013.

$$D_A = \sum_{i=1}^{S} \left(\frac{N_i}{N}\right)^{1/(1-A)}$$

where S is the species richness (total number of species present) in the plot, N is the total number of all species, N_i is the number of the i^{th} species and A is the sequence rank of the diversity measure. The sequence determines the sensitivity to differences in species abundance which is based on the number of each species per square meter. Hill's diversity number fits the three most important diversities well, for $A = 0$, 1 and 2. It was listed as follows:

$$D_0 = S$$

$$D_1 = e^H$$

$$D_2 = \left(D_{\text{Simpson}}\right)^{-1}$$

where H is the Shannon–Wiener diversity index, D_{simpson} is the Simpson diversity index and the other parameters are the same as for the previous formula. D_0 represents the species richness, D_1 and D_2 can be used to assess species diversity and D_1/D_0 or D_2/D_0 can be used to measure species evenness in a community.

One way ANOVAs and a least significant difference (LSD) test were used to compare mean density, coverage, aboveground fresh biomass and Hill's diversity number of vegetation (community, shrub and herb stratum) in T_{2000}, T_{1995}, T_{1987} and CK. To test the predicted vegetation state accuracy in 2005, we used paired tests (Student's t test and Wilcoxon signed rank test) to compare the vegetation parameters in the community, shrub and herb layer in all permanent sites between 2005 and 2013. Differences were considered significant at $P < 0.05$. All analyses were performed with SPSS (Version 16.0, Chicago, IL).

RESULTS

Thirty-eight species distributed across 17 families and belonging to six life forms were discovered across all research sites. Common dominant plant species were shrub *C. microphylla* and annual herbs *Corispermum candelabrum* Iljin and *Setaria viridis* (L.) Beauv. across all experimental sites. Besides, dominant species also had *Bassia dasyphylla* (Fisch. & C. A. Mey.) Kuntze in the T_{2000} and T_{1995}, and *Chenopodium acuminatum* Willd in the T_{1987} and T'_{1987} sites.

Plant density, coverage and biomass in 2005

Significant differences in plant density among the treatments were discovered in 2005 ($P < 0.05$). Community and herb plant density was higher in T_{1987} than in the other three treatments ($P < 0.05$). However, shrub plant density was only higher in T_{1987} than in the CK plot ($P < 0.05$). No other significant differences were detected in the community, shrub and herb layers across all the treatments in 2005.

Community plant coverage was higher in T_{1987} than in the CK plot ($P < 0.05$). Shrub coverage was lower in CK than in the other three treatments ($P < 0.05$), but no significant differences were detected across the three treatments. Herb coverage was higher in T_{1987} and CK than in the T_{2000} and T_{1995} plots ($P < 0.05$). No other significant differences were found in community, shrub and herb layers across all the treatments.

Community plant biomass was higher in T_{1987} than in the T_{1995} and CK ($P < 0.05$) and higher in T_{2000} than in the CK ($P < 0.05$). Shrub biomass was lower in CK than in the other three treatments ($P < 0.05$). Herb biomass was higher in T_{1987} than in the other three treatments ($P < 0.05$). No other significant differences in biomass were detected (all $P > 0.05$; Fig. 1).

Comparison of plant density, coverage and biomass between 2005 and 2013

After eight years of management, plant density did not vary significantly in community, shrub and herb layers under all the treatments (all $P > 0.05$; Table 3, Fig. 1a–c). However, community coverage was significantly increased in the T_{1995} ($P < 0.01$) and CK ($P < 0.05$) plots, but did not vary in the T_{2000} and T_{1987} plots (Fig. 1d). Shrub coverage was also significantly increased in the T_{1995} plots ($P < 0.05$), but did not vary in all other treatment plots (all $P > 0.05$, Fig. 1e). Herb coverage was significantly increased in T_{1995} ($P < 0.01$) and T_{1987} ($P < 0.05$), but did not vary in the T_{2000} and CK plots (both $P < 0.05$, Fig. 1f). Community biomass significantly increased in T_{2000} ($P < 0.05$) and CK ($P < 0.01$), but did not vary in T_{1995} and T_{1987} (Fig. 1g). Shrub biomass significantly increased in T_{2000} ($P < 0.05$) and CK ($P < 0.01$), but did not change in T_{1995} and T_{1987} (Fig. 1h). Herb biomass significantly increased in the T_{1995} ($P < 0.01$) and CK plots ($P < 0.01$), but did not vary in the remaining treatments (Fig. 1i).

Species diversity and evenness in 2005

Much of the species diversity and evenness did not change in the community, shrub and herb layers assessed using SFT in 2005. No significant differences were detected in D_0 among all the treatments, except that it was higher in CK than in T_{2000} with respect to community ($P < 0.05$). It was higher in T_{1987} and CK than in other two treatments with regards to herbs ($P < 0.05$). There were no obvious differences presented between T_{2000} and T_{1995} and between T_{1987} and CK plots. No significant differences were found in D_1 among all the treatments, except it was higher in CK than in T_{1987} in community ($P < 0.05$). No significant differences were detected regarding shrubs among all treatments. No significant differences were found in herbs, except that it was higher in CK than in other three treatments ($P < 0.05$), whereas no other significant differences were detected among the other three treatments.

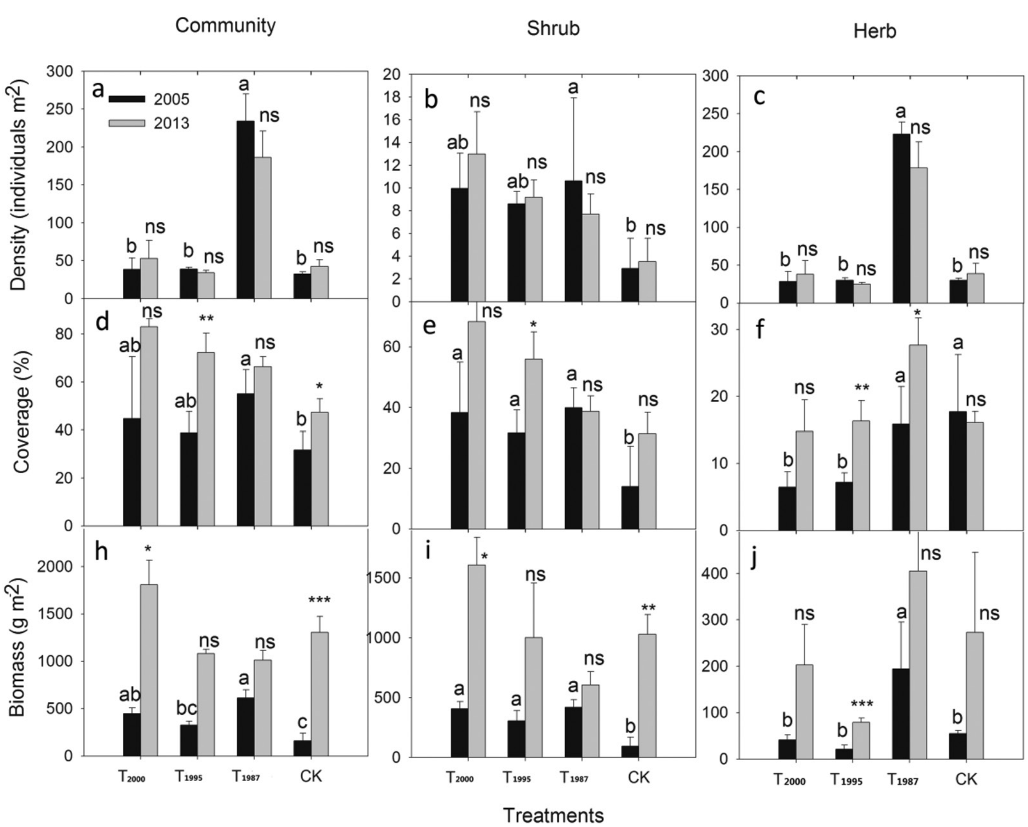

Figure 1. Variations in plant density (individuals m^{-2}), coverage (%) and biomass (g m^{-2}) in the community, shrub and herb strata at four treatment levels before and after eight years of management.

Table 2 **Species composition, plant density and percentage in *C. microphylla* community at four treatment levels in 2005 and 2013**

		Treatment levels											
		T_{2000}			T_{1995}			T_{1987}			CK		
Species name	Life form	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%
AAD	AH										1.0	25.7	20
AAR	SS	0.3	64.7	67	0.8	41.9	73	0.3	39.1	40			
ACO	PH							0.1	44.3	20			
ASI	ABH							0.1	45.0	6.8			
B	AH	3.0	11.1	67	1.7	6.0	73	0.1	6.8	27	1.0	5.4	90
CAC	AH				3.0	6.4	20	147	29.1	87	0.1	3.0	10
CAR	AH	0.9	13.7	40	0.2	10.0	47	1.1	17.5	53			
CC	AH	6.4	12.8	100	9.0	12.7	100	25.2	20.2	100	15.0	4.8	90
CG	AH							0.0	70.0	6.7	0.1	10.0	10
CM	S	1.0	78.9	93	0.8	70.9	100	0.3	111	87	0.1	133	20
CN	BH							0.0	2.0	6.7			
CTH	SS	0.9	10.0	60	0.4	9.6	33				1.4	9.2	40
CV	AH										1.8	6.9	20
DS	AH				0.1	10.0	6.7				0.1	5.0	10
EH	AH							12.4	4.4	93	0.2	2.0	60
EP	AH				0.3	9.1	13						
H	SS							0.1	16.3	13			
LD	SS										0.2	5.0	10
LI	ABH	0.2	48.2	27									
LT	PH	0.1	5.0	6.8									
M	PH				0.1	35.0	6.7	0.2	35.7	33			
PC	PH							6.4	33.6	27	0.3	15.0	20
SF	PH							0.1	80.0	6.7			
SG	S							0.1	120	6.7			
SP	AH										0.1	6.0	10
SV	AH	17.1	20.7	100	15.5	13.7	100	20.3	32.0	73	7.4	9.3	90
TT	AH										1.9	3.2	70

		T'_{2000}			T'_{1995}			T'_{1987}			CK′		
Species name	Life form	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%
AAD	AH										0.2	10.0	13
AAL	AH										0.1	4.0	13
AAR	SS	0.2	22.5	20	0.1	58.3	13	0.1	34.3	20			
ACR	PH										0.3	15.0	6.7
ASC	ABH										0.8	45.0	6.7
ASI	ABH				0.1	120	6.7	0.1	100	13			
B	AH	0.5	15.0	20	0.2	31.7	33						
CAC	AH	0.9	31.1	33	0.9	45.9	60	13.0	50.7	93	0.3	14.7	73
CC	AH	10.0	30.5	80	14.0	20.5	100	139	24.4	100	0.2	14.0	67
CG	AH	0.8	35.0	6.7									
CM	S	0.7	126	100	0.5	119	93	11.4	37.9	93	2.6	154	87
CS	AH							0.1	50.0	6.7	0.8	50.0	87
CTH	SS	0.1	26.5	20	0.1	10.0	6.7						
CTR	PH										0.2	9.5	13
CV	AH										0.2	12.0	13

Table 2. *Continued*

Species name	Life form	Treatment levels											
		T_{2000}			T_{1995}			T_{1987}			CK		
		D	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%	*D*	*H* (cm)	*P*%
DL	AH										0.4	23.0	93
DS	AH										0.2	11.1	47
EH	AH							3.3	50.0	6.7	0.1	4.2	87
EP	AH										0.2	13.0	13
F	PH	0.1	50.0	6.7				0.1	60.0	6.7			
G	AH										0.1	3.0	6.7
H	SS	0.2	98.9	20	0.1	76.3	20	0.1	40.0	6.7			
LD	SS										0.1	7.2	53
LJ	ABH	0.1	50.0	6.7	0.2	69.3	40						
LM	AH										0.4	23.9	13
M	PH							0.1	33.8	13			
PA	AH										0.1	5.0	6.7
PC	PH				1.6	80.0	6.7				0.3	15.0	6.7
SP	AH	2.0	26.9	67	0.3	24.2	40	4.5	26.8	73			
SV	AH	23.7	45.4	100	6.9	50.0	93	7.3	47.0	87	0.2	8.9	100
TT	AH				0.6	22.7	20	0.1	45.0	6.7	0.1	6.0	93
U	T										0.6	35.0	6.7

AAD: *Aristida adscensionis*, AAL: *Amaranthus albus*, AAR: *Artemisia arenaria*, ACO: *Asparagus cochinchinensis*, ACR: *Agropyron cristatum*, ASC: *Artemisia scoparia*, ASI: *Artemisia sieversiana*, B: *Bassia dasyphylla*, CAC: *Chenopodium acuminatum*, CG: *Chenopodium glaucum*, CM: *Caragana microphylla*, CN: *Carduus nutans*, CS: *Cannabis sativa*, CTH: *Cynanchum thesioides*, PA: *Polygonum aviculare*, PC: *Pennisetum centrasiaticum*, SF: *Sophora flavescens*, SG: *Salix gordejevii*, SP: *Salsola pestifer*, SV: *Setaria viridis*, TT: *Tribulus terrestris*, U: *Ulmus pumila*. *D*: mean density of individuals per square meter, *H*: mean height (cm) of individuals, *P*%: frequency.

No significant differences in D_2 were detected in community, shrubs and herbs among all the treatments, except that it was higher ($P < 0.05$) in CK than in T_{1987} with respect to herbs.

No significant differences in D_1/D_0 were detected in community, shrubs and herbs among all the treatments, except that it was higher in T_{2000} than in the T_{1987} and CK in the herb strata ($P < 0.05$). No significant differences were found in D_2/D_0 in community among all the treatments, except that it was higher in T_{2000} than in the T_{1987} in community ($P < 0.05$). No significant differences were detected in shrubs among all the treatments. In addition, no obvious differences were found in herbs among all the treatments, except that it was higher in T_{2000} and T_{1995} than in the T_{1987} plots.

Comparison of species diversity and evenness between 2005 and 2013

After eight years of management, no significant differences were found in D_0 with respect to community, except that it was significantly increased in T_{2000} ($P < 0.05$) and in CK ($P < 0.05$). No significant differences were detected in D_0 in shrubs. Also, no significant differences were found in D_0 in herbs, except that it was increased in CK ($P < 0.01$), but decreased in T_{1987} ($P < 0.05$; Table 3, Fig. 2a–c). No significant differences were found in D_1 in community, shrubs and herbs across all treatments, except it was significantly decreased in CK with regards to herbs ($P < 0.05$). No significant differences were found in D_2 across all the treatments, except it decreased significantly in CK in community ($P < 0.01$) and herbs ($P < 0.01$). No obvious differences were detected in D_2 in shrubs across all the treatments.

No significant differences were detected in D_1/D_0 across all the treatments, except it was significantly decreased in CK in community ($P < 0.001$), shrub ($P < 0.05$) and herb strata ($P < 0.001$; Table 3, Fig. 3a–c). No significant differences were found in D_2/D_0 in community, shrubs and herbs across all the treatments (all $P > 0.05$; Table 3, Fig. 3d–f), except that it was significantly decreased in T_{1987} in community ($P < 0.01$), shrub ($P < 0.01$) and herb strata ($P < 0.01$) and in CK in community ($P < 0.01$) and herb strata ($P < 0.01$).

DISCUSSION

Though Space-for-time substitution (SFT) is the most commonly used method for evaluating vegetation restoration and succession in sand dunes, in our study it was not found to be completely reconcilable with the results from the located observation. This is especially true for simple parameters such as density, coverage and biomass, and the data obtained using SFT may not accurately represent the actual vegetation succession in restoration (Foster and Tilman 2000; Johnson and Miyanishi 2008).

Table 3 Data for variance in plant density, coverage, biomass, species diversity (D_0, D_1 and D_2) and evenness (D_1/D_0 and D_2/D_0) in the community, shrub and herb strata at four treatment levels before and after eight years of management

	Community		Shrub		Herb	
Vegetation parameters	F	P	F	P	F	P
T_{2000}						
Density	0.777	0.428	1.363	0.308	0.530	0.507
Coverage	6.502	0.063	4.850	0.092	7.667	0.050
Biomass	7.922	0.048	10.581	0.031	1.645	0.269
D_0	16.000	0.016	0.250	0.643	1.800	0.251
D_1	0.321	0.601	0.068	0.807	0.048	0.838
D_2	0.187	0.688	0.011	0.922	0.007	0.937
D_1/D_0	2.490	0.190	0.086	0.784	0.749	0.436
D_2/D_0	1.368	0.307	0.165	0.705	0.439	0.544
T_{1995}						
Density	3.665	0.128	0.070	0.804	4.973	0.090
Coverage	23.111	0.009	13.126	0.022	22.238	0.009
Biomass	7.741	0.050	6.772	0.060	61.449	0.001
D_0	1.562	0.279	0.000	1.000	1.316	0.315
D_1	0.220	0.664	1.132	0.347	0.001	0.971
D_2	0.622	0.474	2.007	0.230	0.128	0.739
D_1/D_0	1.694	0.263	2.115	0.220	2.283	0.205
D_2/D_0	2.140	0.217	2.060	0.225	2.882	0.165
T_{1987}						
Density	0.250	0.643	0.533	0.506	0.234	0.654
Coverage	2.866	0.166	0.056	0.824	8.756	0.042
Biomass	3.767	0.124	3.084	0.154	4.246	0.108
D_0	3.500	0.135	0.143	0.725	16.000	0.016
D_1	2.955	0.161	0.042	0.847	3.271	0.145
D_2	2.502	0.189	0.264	0.635	2.632	0.180
D_1/D_0	0.533	0.506	2.599	0.182	0.111	0.755
D_2/D_0	29.408	0.006	26.901	0.007	33.517	0.004
CK						
Density	3.686	0.129	0.073	0.802	2.686	0.162
Coverage	8.115	0.046	4.062	0.114	0.108	0.759
Biomass	67.929	0.001	27.977	0.006	27.977	0.006
D_0	17.286	0.014	0.000	1.000	30.250	0.005
D_1	4.343	0.106	2.801	0.170	19.875	0.011
D_2	38.511	0.003	3.332	0.142	103.836	0.001
D_1/D_0	387.903	0.0004	21.684	0.010	907.793	0.000
D_2/D_0	41.297	0.003	4.204	0.110	80.006	0.001

Test of the predicted accuracy on plant density, coverage and biomass

While SFT assessed the plant density, coverage and biomass as unstable, the located observation method confirmed the actual stability for many treatments in the present study. These results were in consistent with previous findings (Bakker *et al.* 1996; Csecserits *et al.* 2007), indicating that density, coverage and biomass are poorly predicted by SFT when applied in the context of semi-arid sand dune restoration regions. It is possible that extreme drought during the initial planting stage, as well as other extreme environmental hazards, may have resulted in selection and optimization effects that have greatly impacted the simple vegetation parameters (density, coverage and biomass) in the community succession (Csecserits *et al.* 2007; Jentsch *et al.* 2011; Hoover *et al.* 2014). These simple vegetation parameters thus cannot be accurately predicted by SFT. Located observation or other effective methods must therefore be used. Simple vegetation parameters (density, coverage and biomass) were greater in the treatments than in the natural community. The initial density of artificial planted shrubs was greater than in the natural *C. microphylla* community where soil was not disrupted and the canopy opening was small, hampering exotic plant encroachment (Stinson *et al.* 2006).

No obvious differences in dominant species composition were noted across community, shrub and herb strata, which is consistent with other results from studies on moving sand dunes (Cao *et al.* 2004). In contrast, other studies have found that the dominant species composition to be greatly altered following long-term grazing exclusion (Su *et al.* 2004; Zhao *et al.* 2007). Significant differences in species number were observed across the research sites, and may be attributed to alterations in competitive hierarchies and resources as well as differences in the microenvironment (e.g. seed resources, microclimate; Hager 2004; Hirota *et al.* 2011). Such slight variations in the dominant species imply that there are a few dominant species occupying the greatest density with little recruitment of new plants in the research sites. Coverage and biomass in the community, shrub and herb strata were increased with more biennial and perennial plants being recruited into the community (Table 1; Jeddi and Chaieb 2010). Plant density and coverage in the community, shrub and herb strata are important measures of community structure (Ruiz-Jaén and Aide 2005; Wortley *et al.* 2013). These findings indicate that community structure and species composition are poorly predicted with SFT and better estimation methods are required.

Test of the predicted accuracy on plant species diversity and evenness

Species diversity and evenness are important parameters for assessing vegetation restoration conditions (Wilkins *et al.* 2003; Martin *et al.* 2005). Using SFT, most species diversity and evenness estimates in the community, shrub and herb strata were stable or even slightly decreased in the treatments (Figs 2 and 3), and these findings are consistent with the located experiment results. Thus, SFT was appropriate for species diversity and evenness evaluation with respect to post planting. Our results indicate that these sophisticated vegetation parameters (species diversity and evenness) are well predicted by SFT in secondary succession in semi-arid sandy grasslands, and these results confirm that the vegetation community was stable. Other studies indicate that species diversity and evenness

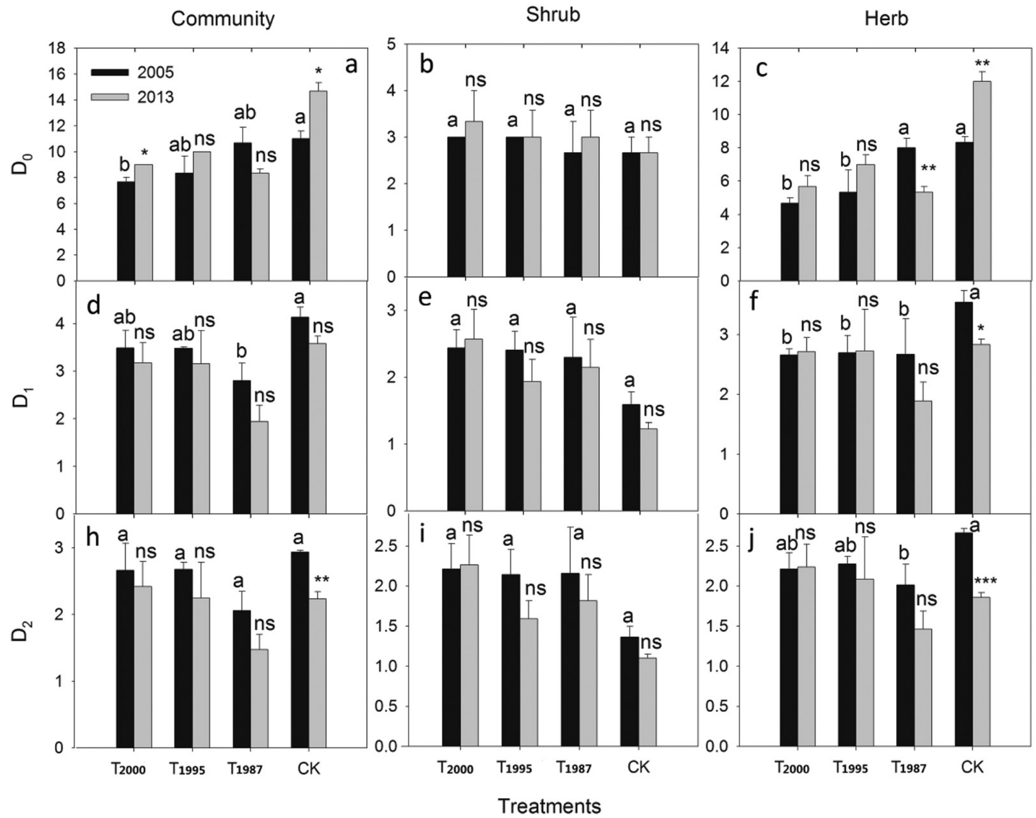

Figure 2. Plant species diversity (D_0, D_1 and D_2) variations in four treatment levels before and after eight years of management.

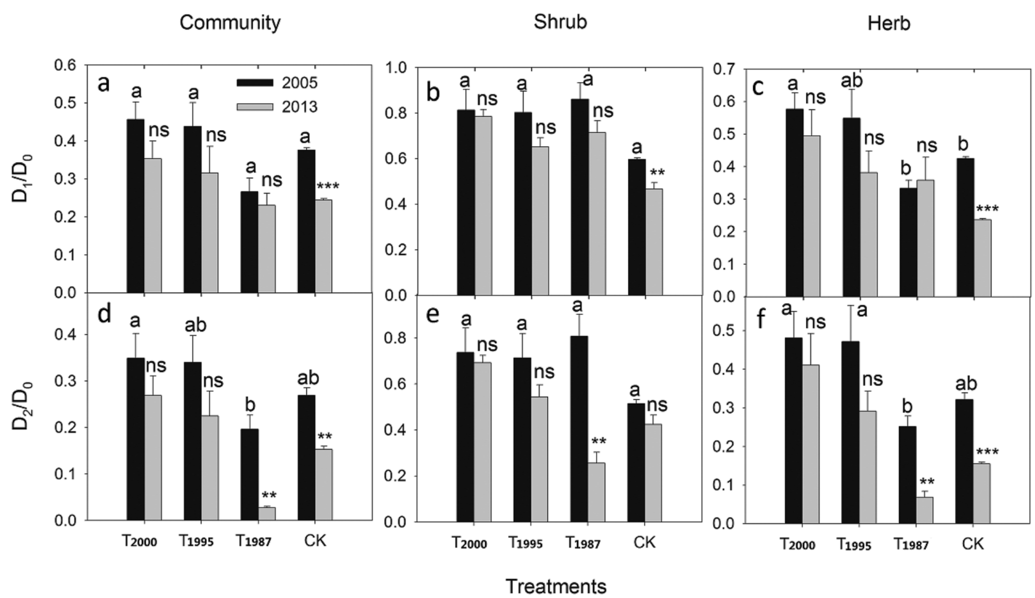

Figure 3. Plant species evenness (D_1/D_0 and D_2/D_0) variations in four treatment levels before and after eight years of management.

can be stable when it has reached a climax community in the local environment (Connell and Slatyer 1977; Chase 2003). The community state mainly depends on microclimate, soil properties and the native natural community (Chase 2003), and with suitable climate and soil conditions, the community can have high species diversity and evenness. In contrast, in poor conditions, the community can only achieve and maintain a relatively low level of species diversity and evenness.

Other findings indicate that species diversity and evenness in semi-arid degraded grasslands are greater in the mid-stage of restoration, followed by a slight decrease (Jing *et al.* 2014). This can be attributed to competition for light and water resources resulting in a decrease in herbaceous vegetation (Silvertown 2004; Farrior *et al.* 2013).

When community stability has been achieved, the land can be used in a sustainable manner and other management practices (e.g. moderate grazing or mowing) can be employed for conservation. Currently, we are able to determine the restoration status of the vegetation, as well as a suitable method for its prediction. Future studies should investigate the predicted accuracy of the state of soil physical-chemical and microbial properties using SFT and determine the best restoration and utilization assessment in the PSC sites of the sand dunes.

Based on eight-year located observation experiments used to analyze a shrub planting age sequence, we concluded that SFT is an inadequate predictor of simple vegetation parameters (community structure, species composition and biomass), but does accurately predict sophisticated vegetation parameters (species diversity and evenness). Located experiments should be used to increase SFT accuracy in succession assessments rather than relying only on the use of simple descriptive terms.

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