Supporting Information for

Disentangling the Influential Factors Driving NPP Decrease in Shandong Province: An Analysis from Time Series Evaluation Using MODIS and CASA Model

Introduction

This supporting document provides the calculation of solar radiation from solar duration observation data, look-up tables of coefficient settings in the CASA model, area statistics of NPP Changes, a comparison of NPP estimation results, and the partial dependence plots derived from Random Forest modelings.

Supplementary S1. The SOL calculation based on sunshine duration

Daily sunshine duration data from 62 meteorological stations across Shandong Province and surrounding regions were acquired from the China Meteorological Administration (CMA) for the period 2000-2019. This data formed the basis for estimating surface solar radiation (SOL). An inverse distance weighted (IDW) interpolation was employed to generate daily sunshine duration raster images with a spatial resolution of 250 meters x 250 meters. This upscaled the point data from the meteorological stations to a continuous spatial representation suitable for further analysis. To estimate surface solar radiation, an empirical relationship between sunshine duration and the sunshine percentage ratio was established. This relationship was derived through regression analysis utilizing historical years of measured surface solar radiation data from China. The specific calculation process is as follows:

$$SOL = S_0 \times [a_n + b_n \times \frac{n}{N}] \quad (S1)$$

where a_n and b_n are constants, specific values refer to Wang et al [1], n is the actual sunshine duration (h), N is the possible sunshine duration (h), and n/N is the sunshine percentage; S_0 is the astronomical daily total radiation ($MJ.m^{-2}.d^{-2}$), which is a function of geographic latitude, solar declination, sunset hour angle, solar constant, and the average distance between the Earth and the Sun.

$$S_0 = \frac{TI_0}{\pi\rho^2}(\omega_0 sin\Phi sin\delta + cos\Phi cos\delta cos\omega_0) \quad (S2)$$

where T is cyclicality(24×60×60), I_0 is solar constant (13.67×10^{-4} $MJ.m^{-2}.d^{-2}$), ρ is the average distance between the Earth and the Sun， ω_0 is geographic latitude， φ is sunset hour angle, δ is solar declination.

$$\rho = \sqrt{\frac{1}{1+0.033\cos(\frac{2\pi J}{365})}} \quad (S3)$$

$$\delta = 0.409\sin(0.0172J - 1.39) \quad (S4)$$

$$\omega_0 = \arccos(-\tan\Phi\tan\delta) \quad (S5)$$

where J is Julian day, January 1st is taken as 0, and December 31st is taken as 364.

Table S1. The look-up table of $NDVI_{max}$, $NDVI_{min}$, and LUE_{max} values for different land cover types that adopted from Zhu *et al.*,[2].

Vegetation type	$NDVI_{max}$	$NDVI_{min}$	SR_{max}	SR_{min}	LUE_{max}
Deciduous needle-leaf forest	0.738	0.023	6.63	1.05	0.485
Evergreen needle-leaf forest	0.647	0.023	4.67	1.05	0.389
Evergreen broad-leaf forest	0.676	0.023	5.17	1.05	0.985
Deciduous broad-leaf forest	0.747	0.023	6.91	1.05	0.692
Sparse woods	0.636	0.023	4.49	1.05	0.475
Wetlands	0.634	0.023	4.46	1.05	0.542
Grassland	0.634	0.023	4.46	1.05	0.542
Impervious surfaces	0.634	0.023	4.46	1.05	0.542
Waterbody	0.634	0.023	4.46	1.05	0.542
Bare area	0.634	0.023	4.46	1.05	0.542
Farmland	0.634	0.023	4.46	1.05	0.542

Table S2. The area **s**tatistics of NPP changes by land cover types (unit: km^2)

Change type	Forest	Grassland	Farmland	Wetland	Waterbody	Impervious surface
Increase	2186.3	7202.9	81882.9	387.4	686.2	10.4
Gradual decline	18.6	83.1	6685.5	216.6	653.1	4.0
Abrupt loss	276.9	427.7	2844.3	281.4	633.2	1.1

Table S3. Comparison of NPP estimation results with other studies in Shandong province

Methods	CASA	CASA	MOD17A3	MOD17A3	MOD17A3	VPM
Period	2001-2010	2000-2005	2000-2014	2000-2015	2000-2019	2000-2015
Other study	200-500	252.10	368.94	501-583	377.0	711.67
This study	485.35	463.4	489.27	491.11	503.45	491.11
Reference	Chao *et al.*, (2013) [3]	Tian *et al.*, (2010) [4]	Li *et al.*, (2019) [5]	Liu *et al.*, (2019) [6]	Lu *et al.*, (2023) [7]	Wang *et al.*, (2020) [8]

References

1. Wang, J.; Feng, J.; Yuan, A. Calcuation and Distributive Characteristics of Solar Radiation in Shandong Province. *Meteorol. Sci. Technol.* **2006**, 98–101, doi:10.19517/j.1671-6345.2006.01.022.
2. Zhu, W.; Pan, Y.; Zhang, J. Estimation of net primary productivity of chinese terrestrial vegetation based on remote sensing. *J. Plant Ecol.* **2007**, 413–424.
3. Chao, Z.; Zhang, P.; Wang, X.; Qian, J. Terrestrial net primary production and its spatio-temporal patterns in Shandong Province during 2001-2010. *Pratacultural Sci.* **2013**, *30*, 829–835.
4. Tian, Y.; Guo, Y.; Zhang, P.; Wang, L.; Yang, Y.; Li, H. Relationship of regional net primary productivity and related meteorological factors. *Pratacultural Sci.* **2010**, *27*, 8–17.
5. Li, H.; Zhang, A.; Hou, X. Ｒesponse of Vegetation Net Primary Productivity to Land Cover Change from 2000 to 2014 in Shandong Province,China. *J. Ludong Univ. Nat. Sci. Ed.* **2019**, *35*, 157-163+192.
6. Liu Y.; Zhang Jun; Zhang C.; Xiao B.; Liu L.; Cao Y. Spatial and temporal variations of vegetation net primary productivity and its responses to climate change in Shandong Province from 2000 to 2015． . *Chin. J. Ecol.* **2019**, doi:10.13292/j.1000-4890.201905.033.
7. Lu, Z.; Chen, P.; Yang, Y.; Zhang, S.; Zhang, C.; Zhu, H. Exploring Quantification and Analyzing Driving Force for Spatial and Temporal Differentiation Characteristics of Vegetation Net Primary Productivity in Shandong Province, China. *Ecol. Indic.* **2023**, *153*, 110471, doi:10.1016/j.ecolind.2023.110471.
8. Wang, H.; Wang, W.; Shang, L. Spatial and temporal pattern of cultivated land productivity in Shandong Province from 2000 to 2015. *J. China Agric. Univ.* **2020**, *25*, 128–138.

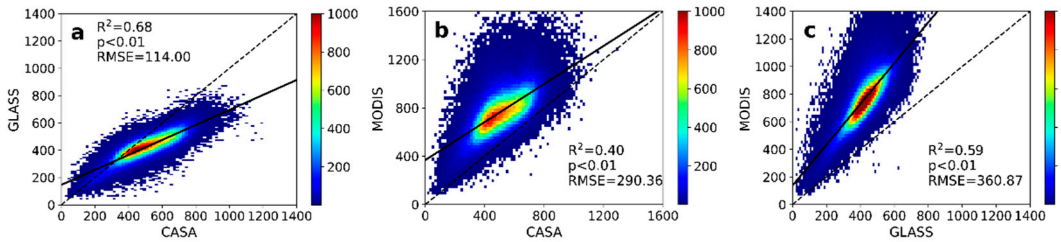

Figure S1. The density scatter plot and linear regression (solid lines) between CASA estimates and GLASS product (a), between CASA estimates and MODIS product (b), and between GLASS product and MODIS product (c). A 1:1 correlation line (dashed line) is added for reference. The red color indicates a higher density of points, and the blue color indicates a lower density. Abbreviations: CASA - Carnegie-Ames-Stanford Approach, GLASS - Global LAnd Surface Satellite, RMSE - Root Mean Squared Error.

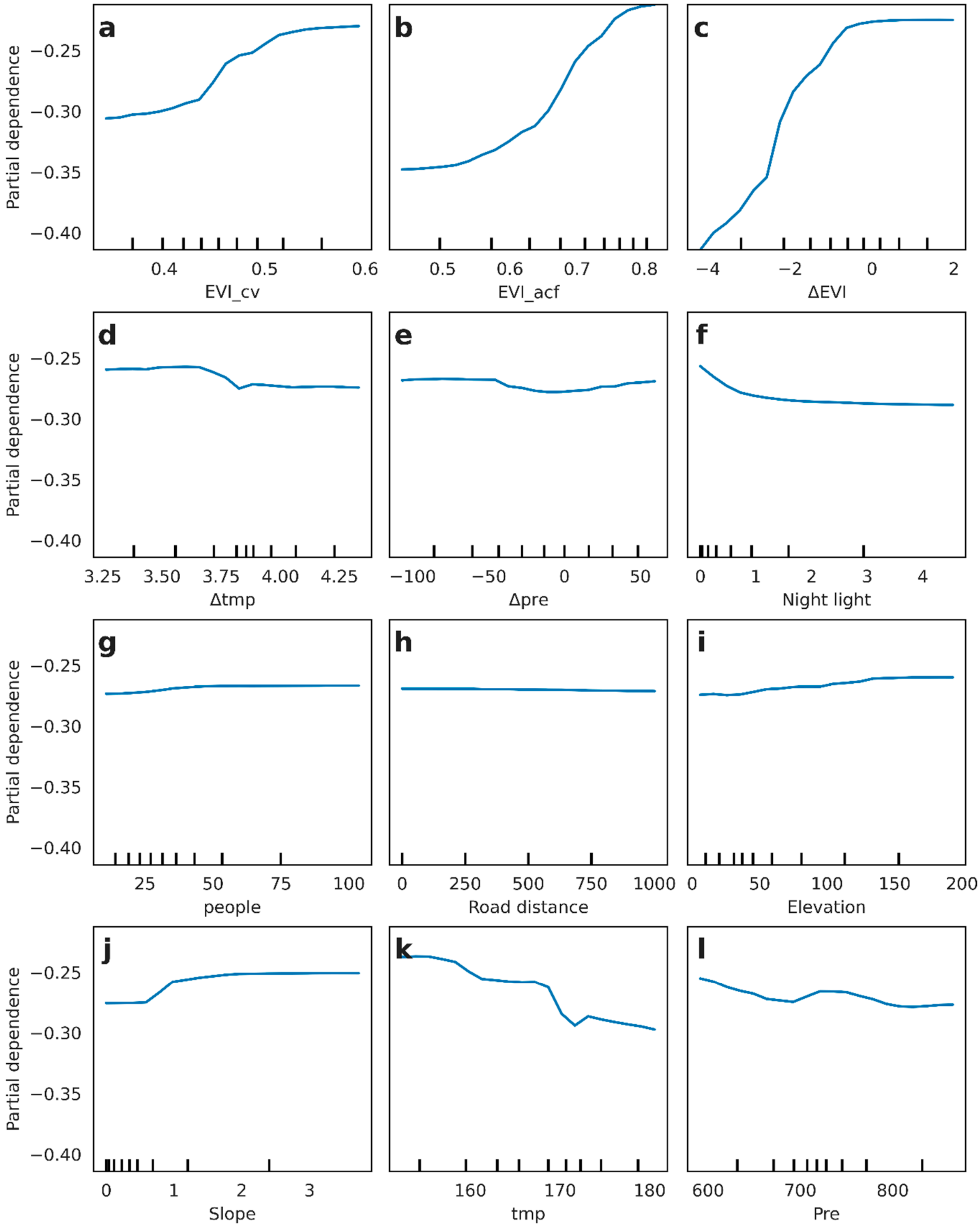

Figure S2. The partial dependence curves of explanatory variables (names see axis) on regulating the intensity of gradual NPP decline in farmland from 2000 to 2019 of Shandong province.

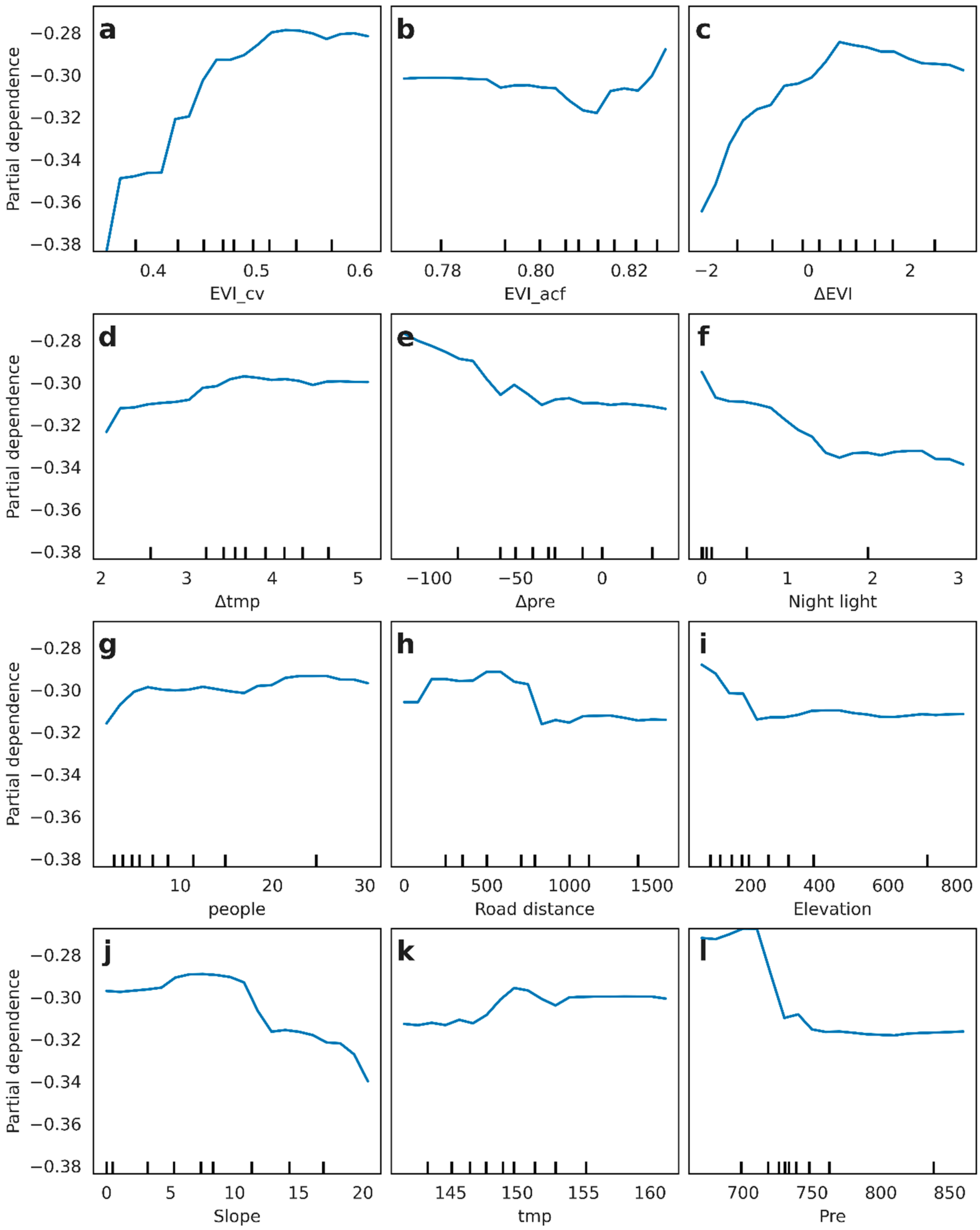

Figure S3. The partial dependence curves of explanatory variables (names see axis) on regulating the intensity of gradual NPP decline in forests from 2000 to 2019 of Shandong province.

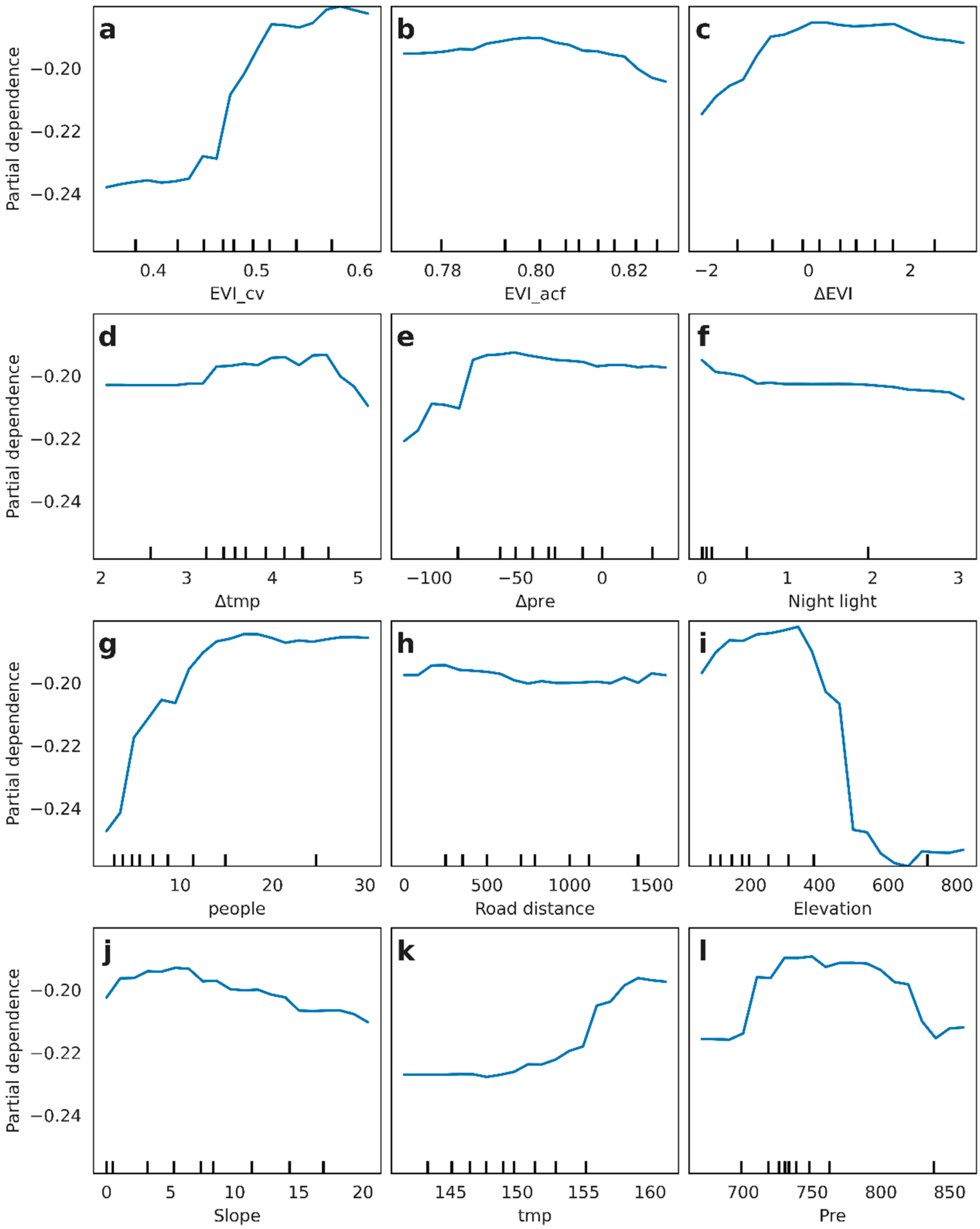

Figure S4. The partial dependence curves of explanatory variables (names see axis) on regulating the intensity of gradual NPP decline in grassland from 2000 to 2019 of Shandong province.

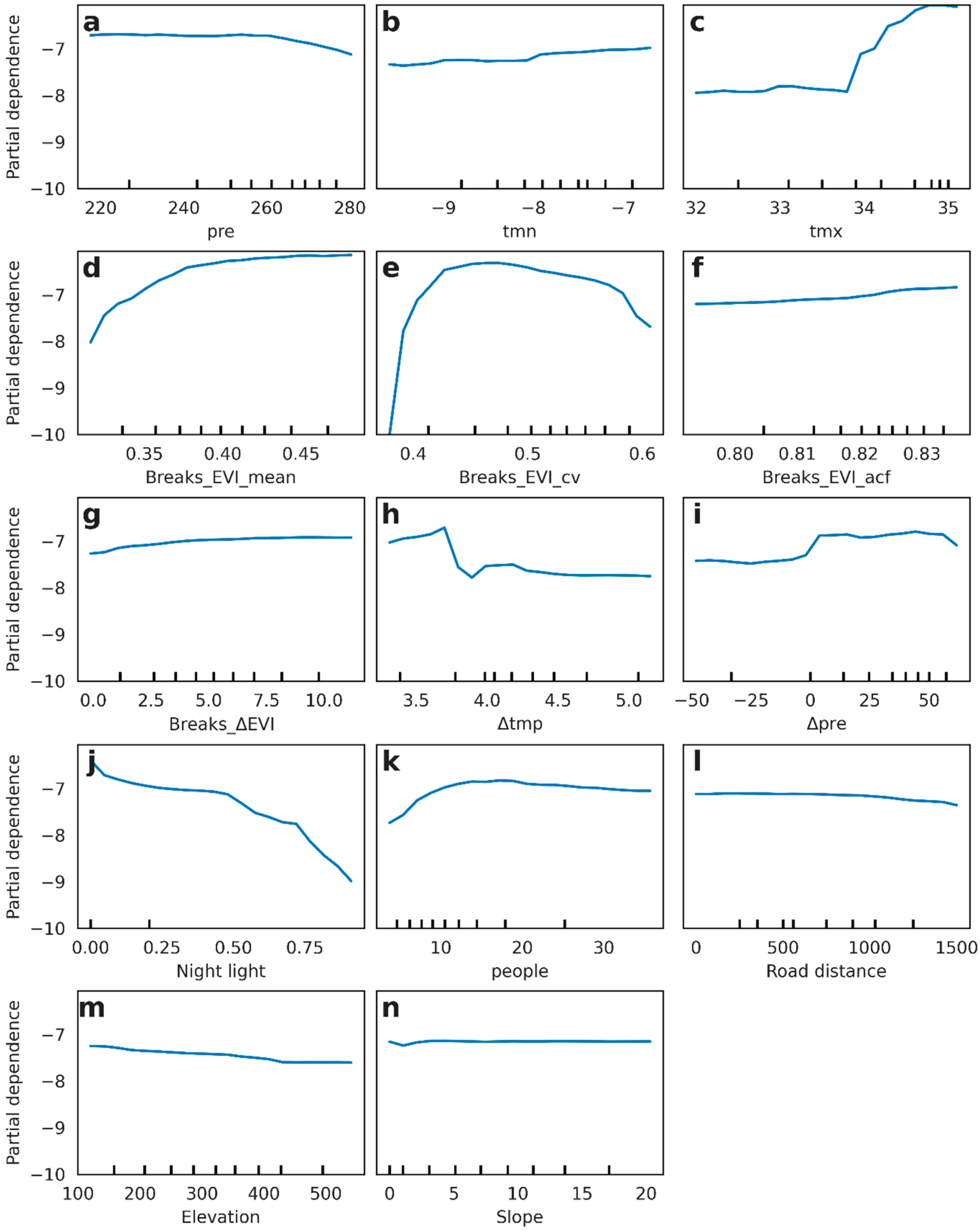

Figure S**5**. The partial dependence curves of explanatory variables (names see axis) on regulating the magnitude of abrupt NPP loss in farmland from 2000 to 2019 of Shandong province.

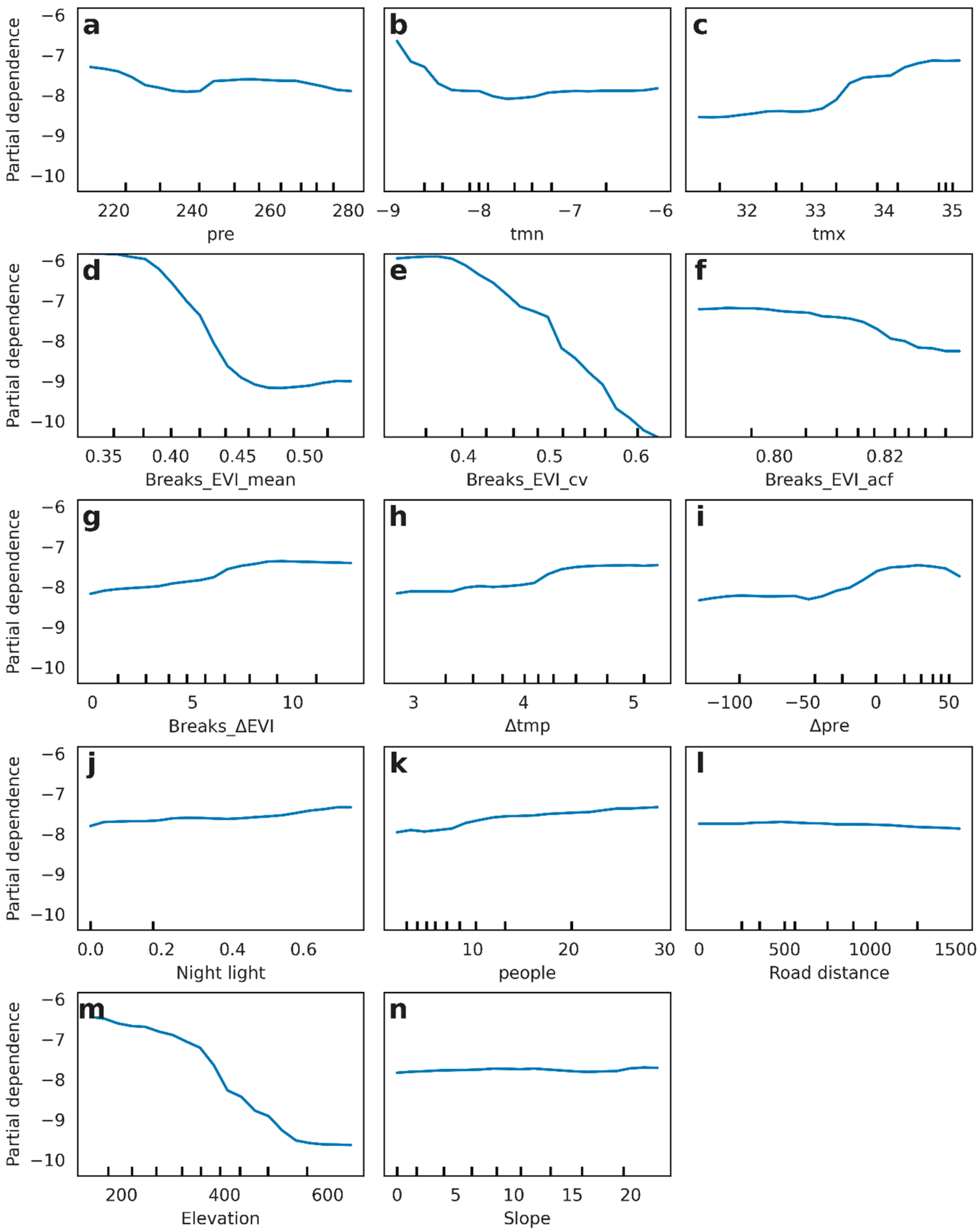

Figure S6. The partial dependence curves of explanatory variables (names see axis) on regulating the magnitude of abrupt NPP loss in forests from 2000 to 2019 of Shandong province.

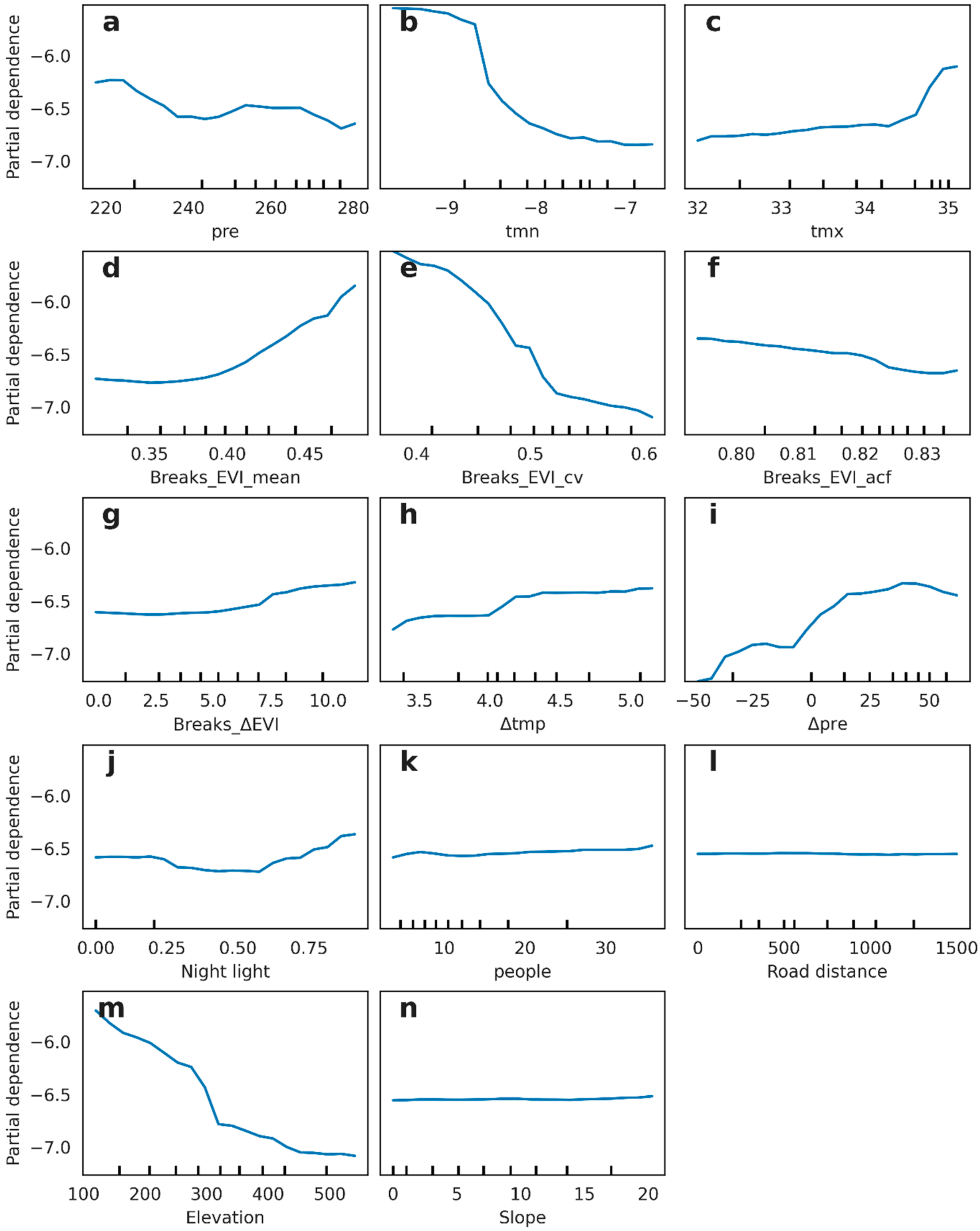

Figure S7. The partial dependence curves of explanatory variables (names see axis) on regulating the magnitude of abrupt NPP loss in grassland from 2000 to 2019 of Shandong province.