Supplementary Information for
Integrating Agricultural and Ecotourism Development: A Crop Cultivation Suitability Framework Considering Tourists' Landscape Preferences in Qinghai Province, China

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Totally 15 pages include 3 tables, 7 figures and 1 questionnaire

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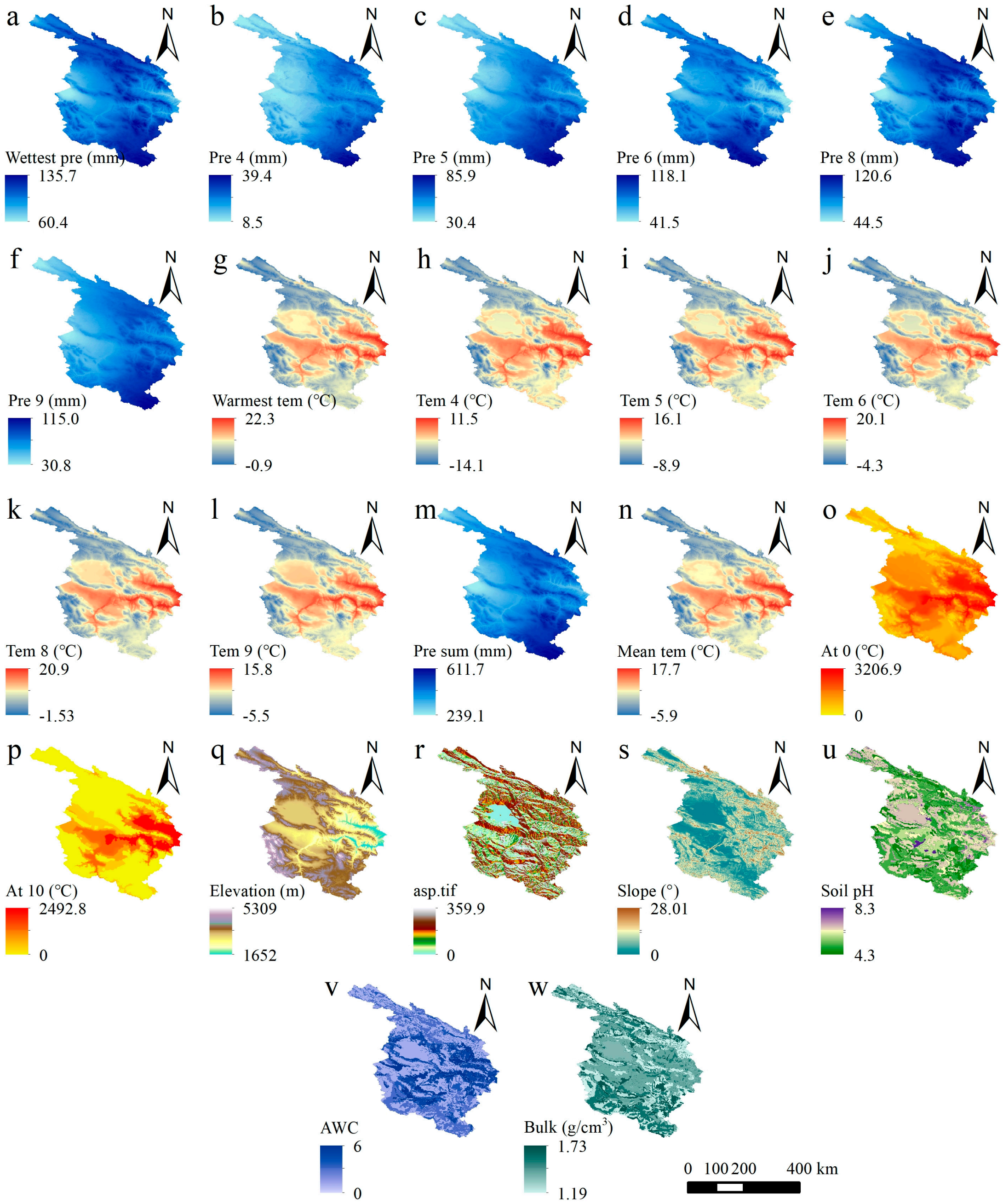
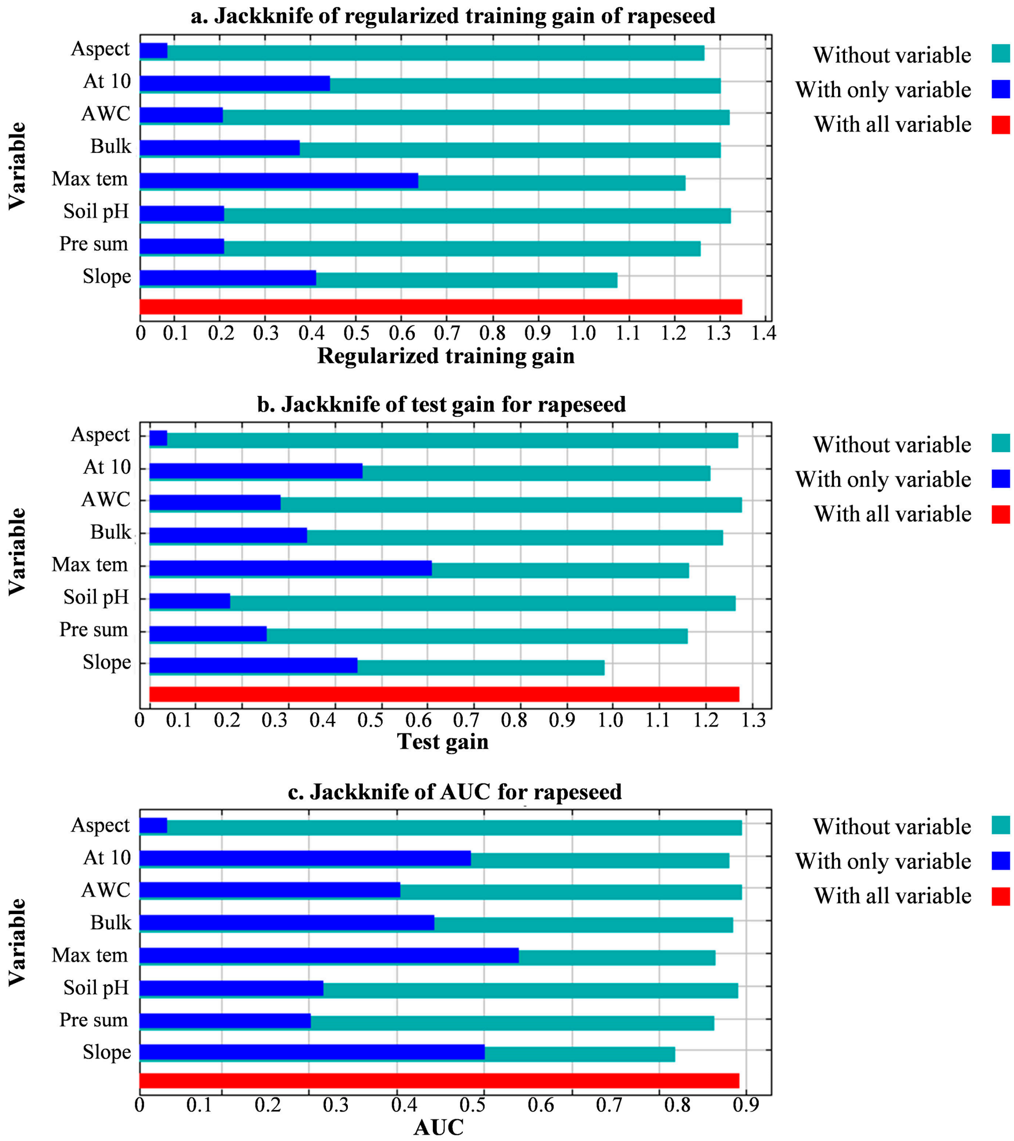


Supplementary Figure S1. Spatial distribution of potential environmental factors affecting rapeseed cultivation. "Wettest pre" represents the precipitation (mm) of wettest month, i.e., precipitation in July (a). "Pre 4, 5, 6, 8, 9" represent the monthly precipitation (mm) of April, May, June, August, and September, respectively (b-f). "Warmest tem" represents the temperature of warmest month (℃), i.e., temperature in July (g). "Tem 4, 5, 6, 8, 9" represent the monthly temperatures for April, May, June, August, and September, respectively (h-i). "Pre sum" indicates the total precipitation (mm) from April to September (m). "Mean tem" indicates average monthly temperature (℃) from April to September (n). "At 0" and "At 10" represent ≥0 ℃ and ≥10 ℃ accumulated temperature (o and p). "AWC" represents the available soil water capacity class (v). “Bulk” represents the soil bulk density (w).

Supplementary Table S1. VIF values for eight variables entered the Maxent model.

		Dependent variables								
		At 10	Max tem	Pre sum	Aspect	Slope	Soil pH	AWC	BULK	Mean VIF
Independent variables	At 10	-	1.33	3.62	3.76	3.44	3.76	3.69	3.75	3.34
	Max tem	1.33	-	3.77	3.77	3.38	3.75	3.73	3.76	3.36
	Pre sum	1.19	1.23	-	1.21	1.19	1.21	1.23	1.23	1.21
	Aspect	1.03	1.03	1.01	-	1.03	1.03	1.03	1.03	1.03
	Slope	1.10	1.08	1.16	1.20	-	1.19	1.20	1.20	1.16
	Soil pH	1.20	1.20	1.18	1.20	1.19	-	1.20	1.10	1.18
	AWC	1.49	1.51	1.52	1.52	1.52	1.52	-	1.18	1.47
	BULK	1.44	1.44	1.44	1.44	1.43	1.32	1.11	-	1.37

Note: “At 10” represents ≥10 °C accumulated temperature, “Max tem” represents the temperature of the warmest month, “Pre sum” represents the total amount of precipitation from April to September, “AWC” represents the Available soil water capacity class, “bulk” represents the soil bulk density.



Supplementary Figure S2. Jackknife test results of regularized gain of rapeseed (a), test gain of rapeseed (b) and AUC (c) for variable importance. "At 10" represents ≥ 10 °C accumulated temperature, "Max tem" represents the temperature of the warmest month, "Pre sum" represents the total amount of precipitation from April to September, "AWC" represents the Available soil water capacity class, "bulk" represents the soil bulk density.

Figure S2 shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is Max tem, which therefore appears to have the most useful information by itself (figure S2c). The environmental variable that decreases the gain the most when it is omitted is slope, which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over 10 replicate runs. The Figure S2b shows the same jackknife test, using test gain instead of training gain. Note that conclusions about which variables are most important can change for test data. Figure S2c shows the same jackknife test, using AUC on test data.

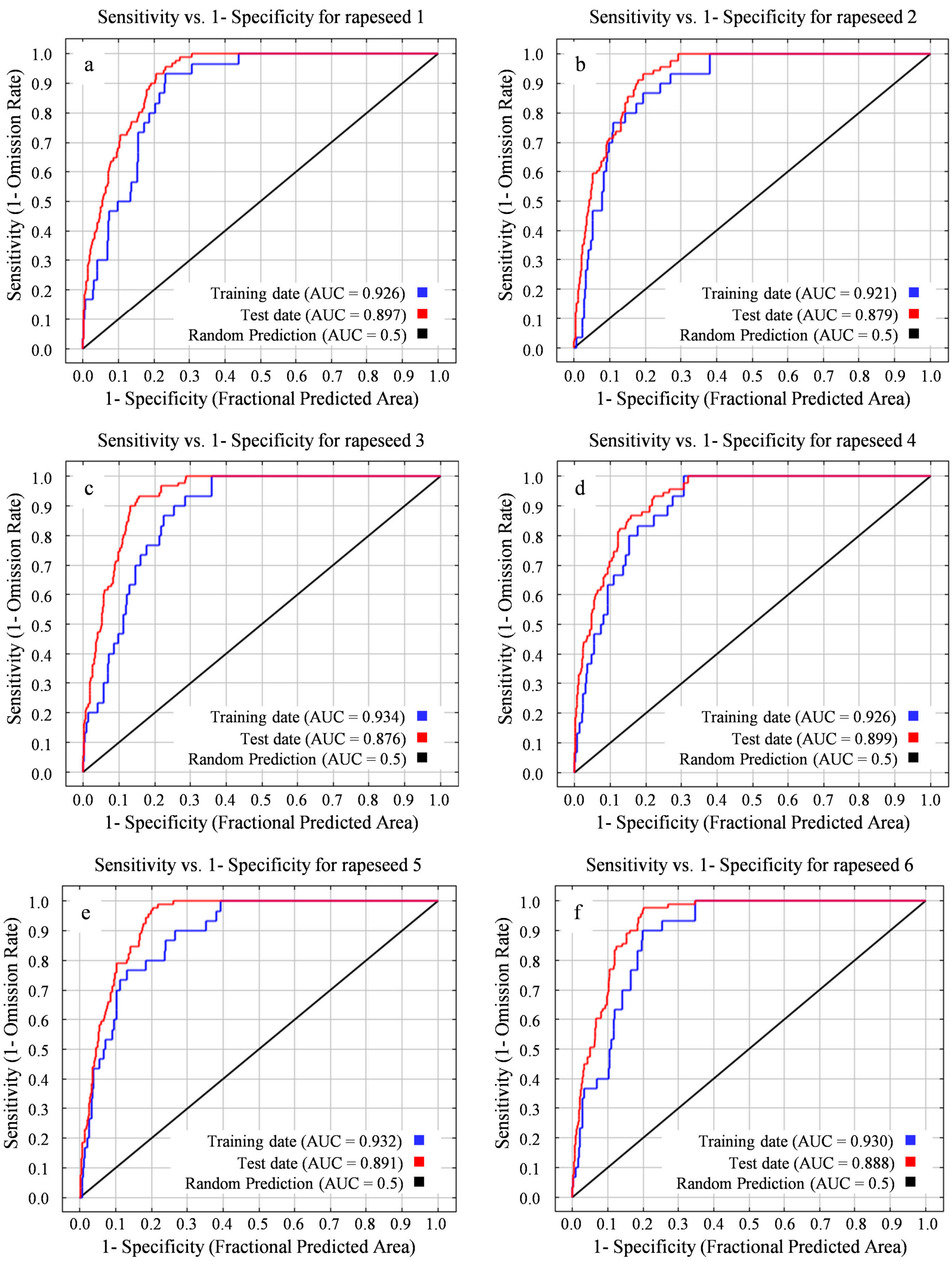
Supplementary Table S2. Catalogue of state class scenic spots of study area.

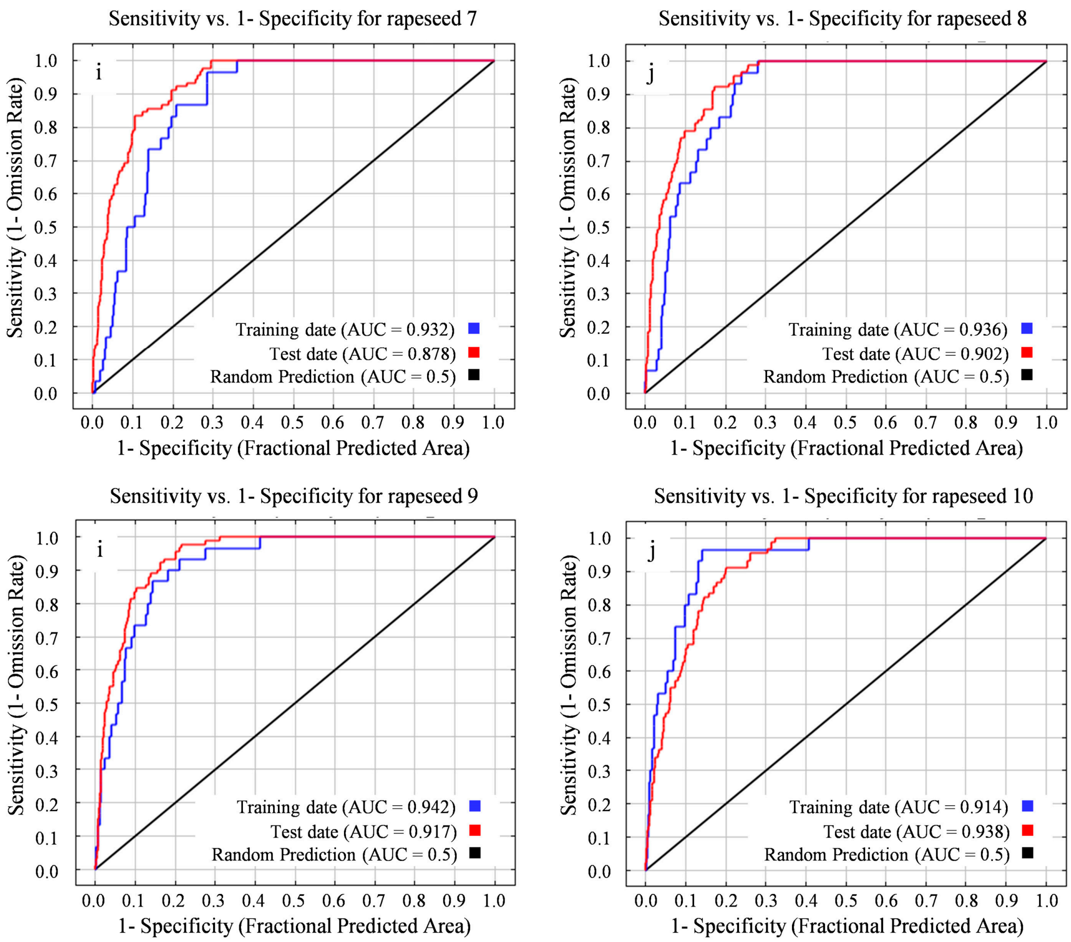
Scenic spot class	No.	Name
AAAAA State Class Scenic Spots	1	Qinghai Lake — Erlangjian Scenic Spot
	2	Qinghai Lake — Xiannv Scenic Spot
	3	Qinghai Lake — Shadao Scenic Spot
	4	Qinghai Lake — Jinshawan Scenic Spot
	5	Qinghai Lake — Bird Island Scenic Spot
	6	Amidongsuo Scenic Spot
	7	Huzhu Tu Homeland Park Scenic Spot
AAAA State Class Scenic Spots	8	Xunhua Sala Nationality Gardens
	9	Jinyintan Pasture
	10	Menyuan Hundred Miles of Rapeseeds Flower Field
	11	Datong Laoyeshan Mountain
	12	Kanbula Area
	13	Longyangxia Reservoir
	14	Minhe Yonglu Kangeda Area
	15	Qilian Mountains
	16	Huzhu North Mountain National Forest Park
AAA State Class Scenic Spots	17	Datong Niangniang Mountain
	18	Qinghai Riyue Mountain
	19	Xiaqun Temple Forest Park
	20	Scenic Area Huangyuan Daheigou Scenic Area
	21	Datong National Forest Park's Kite Ditch
	22	Hualong Benkanggou Scenic Spot
	23	Menyuan Juyanggou Scenic Spot
	24	Hualong Xiongxiangang Mountain Zoology Scenic Area
AA State Class Scenic Spots	25	Minghe Tianjingxia- Songshan Virgin Forest

Supplementary Table S3. Estimates of relative contributions of the environmental variables to the Maxent model.

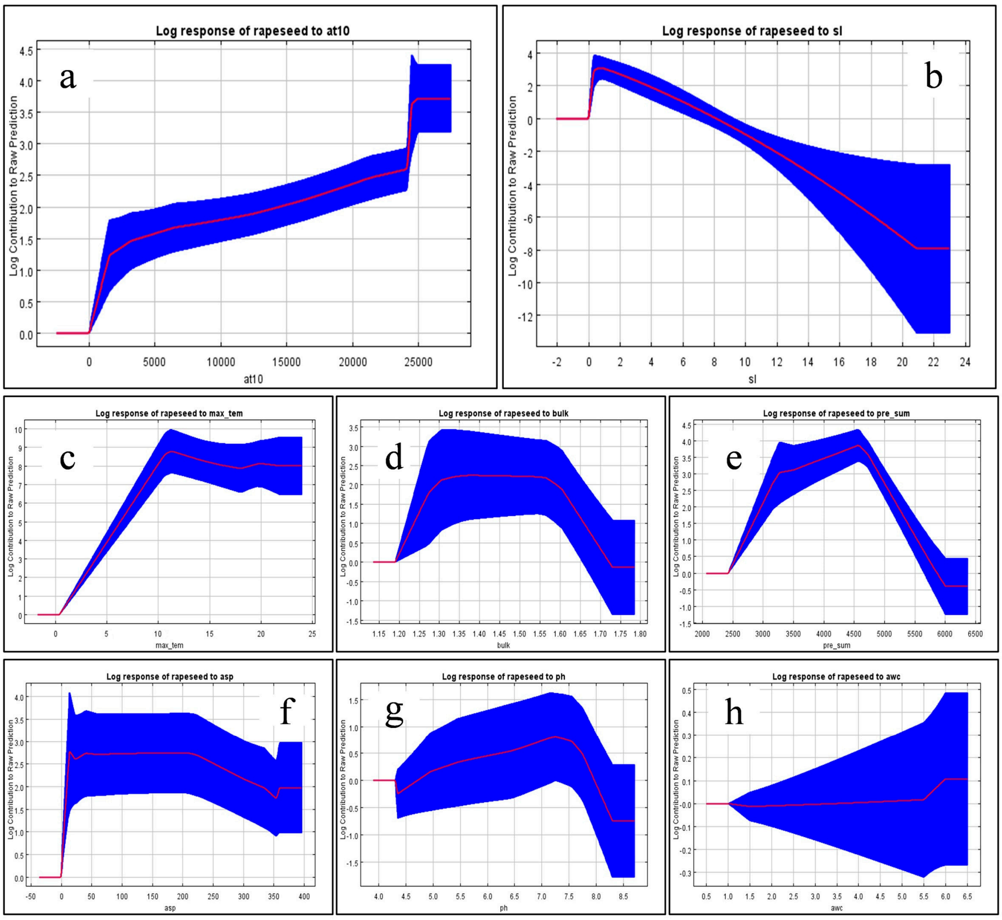
Variable	Percent contribution	Permutation importance
≥10℃ accumulated temperature (℃·d)	27.9	6.9
Slope (°)	21.5	23.2
Temperature of warmest month (℃)	17.8	38.2
Soil bulk density	9.9	7.1
Total precipitation (mm) from April to September	8	12.9
Aspect (°)	7	8.1
Soil PH	5.1	2
Available soil water capacity class	3	1.7

Table S3 gives estimates of relative contributions of the environmental variables to the Maxent model. Values shown are averages over 10 replicate runs.


Sensitivity vs. 1- Specificity for rapeseed 1
a
Sensitivity (1- Omission Rate)
1- Specificity (Fractional Predicted Area)
Training date (AUC = 0.926)
Test date (AUC = 0.897)
Random Prediction (AUC = 0.5)
Sensitivity vs. 1- Specificity for rapeseed 2
b
Training date (AUC = 0.921)
Test date (AUC = 0.879)
Random Prediction (AUC = 0.5)
Sensitivity vs. 1- Specificity for rapeseed 3
c
Training date (AUC = 0.934)
Test date (AUC = 0.876)
Random Prediction (AUC = 0.5)
Sensitivity vs. 1- Specificity for rapeseed 4
d
Training date (AUC = 0.926)
Test date (AUC = 0.899)
Random Prediction (AUC = 0.5)
Sensitivity vs. 1- Specificity for rapeseed 5
e
Training date (AUC = 0.932)
Test date (AUC = 0.891)
Random Prediction (AUC = 0.5)
Sensitivity vs. 1- Specificity for rapeseed 6
f
Training date (AUC = 0.930)
Test date (AUC = 0.888)
Random Prediction (AUC = 0.5)



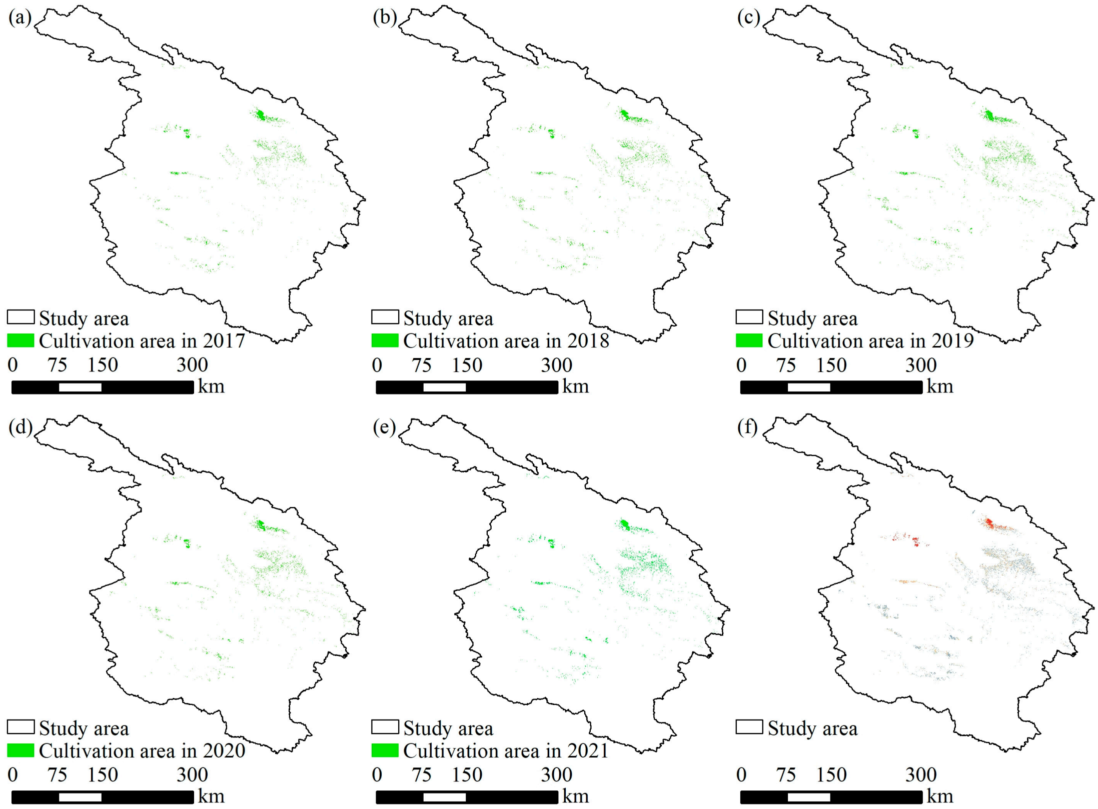
Supplementary Figure S3. Receiver operating characteristic (ROC) curves for the training and test sets of rapeseeds. Supplementary Fig. 1a-j represent 10 replicates.



Supplementary Figure S4. Effect of environmental variables on Maxent's prediction results. Supplementary Fig. 2a-j represent ≥10 °C accumulated temperature, slope, temperature of warmest month, soil bulk density, total precipitation from April to September, aspect, soil pH, available soil water capacity class, respectively.

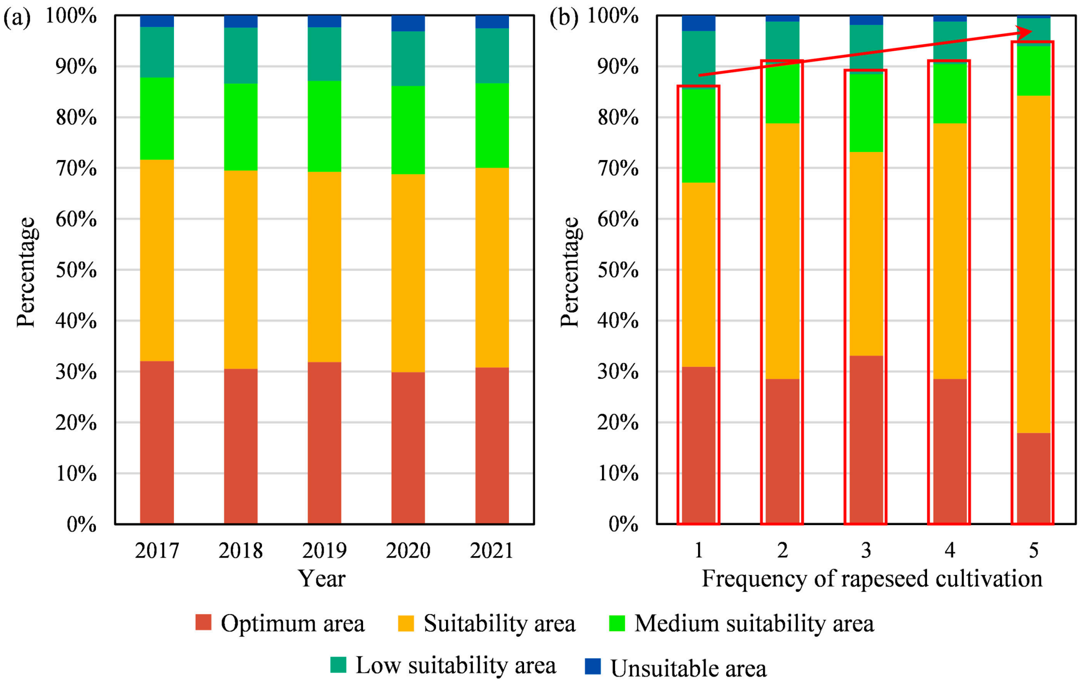
The curves in the figure show the effect of environmental variables on Maxent's prediction results. The red curve shows the mean response of the 10 replicate Maxent runs and the blue area indicates +/− one standard deviation of the mean. Figures a to j represent the response of the distribution probability of rapeseed under changes in eight environmental factors, ≥10 °C accumulated temperature, slope, temperature of warmest month, soil bulk density, total precipitation from April to September, aspect, soil pH, available soil water capacity class, respectively.

The effect of different environmental factors on the distribution of rapeseed varies. The probability of rapeseed distribution increases as the ≥10 °C accumulated temperature increases. When the slope is between 0° and 8°, there is a positive contribution to the rapeseed distribution. However, the greater the slope, the lower the contribution. In particular, slopes greater than 8 degrees make a negative contribution to the probability of rapeseed distribution. The probability of rapeseed distribution is highest when the temperature of warmest month is greater than 10°C. The optimum soil bulk density range is between 1.3 and 1.6 g/cm^3. The growing season is most suitable for rapeseed when the total precipitation is between 3200 and 5000 mm. When the total precipitation exceeds 5800 mm, it plays a negative role in the distribution of rapeseed. The growing season is most suitable for rapeseed when the total precipitation is between 3200 and 5000 mm. When the total precipitation exceeds 5800 mm, it plays a negative role in the distribution of rapeseed. The change in aspect has less influence on the probability of rapeseed distribution. The aspect is represented by a positive number of degrees between 0 and 359.9 and is measured clockwise with north as the reference direction. The contribution to the distribution of rapeseed decreases when the aspect is above 220°, i.e. when the slope is facing west. Soil pH values between 4.5 and 8 are suitable for rapeseed growth. The probability of rapeseed distribution is highest at around pH 7.2. The available soil water capacity class has a small effect on the distribution of rapeseed in the study area. There was no significant difference in the probability of rapeseed distribution contribution to its variation.



Supplementary Figure S5. Areas of rapeseed cultivation from 2017 to 2021 (a to e) and frequency (f) of cultivation over the five-year period.

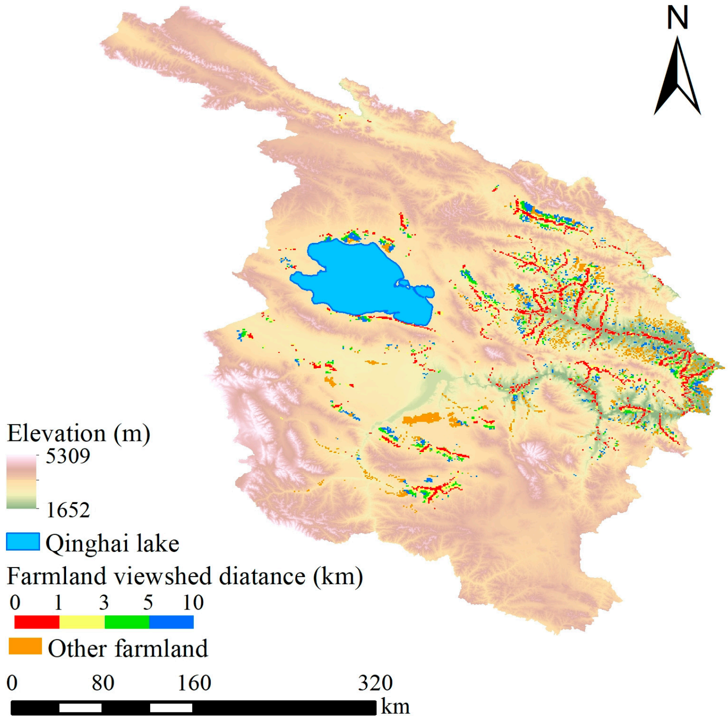
Figure S5 illustrates the distribution of rapeseed cultivation within the study area from 2017 to 2021. In terms of the spatial distribution, we observed a significant overlap between the rapeseed planting areas and the optimum area, suitability area, and medium suitability area during these five years (Figure 5). Furthermore, we also conducted an analysis of rapeseed cultivation frequency between 2017 and 2021. The findings reveal that approximately 2361 km^2 of the study area had been planted with rapeseed within this five-year period. The distribution of cultivation frequencies, ranging from 1 to 5, was as follows: 5.82%, 5.39%, 15.08%, 29.72%, and 43.99%, respectively.



Supplementary Figure S6. Area (a) and frequency area (b) statistics of rapeseed cultivation in different environmental suitability areas from 2017 to 2021.

By calculating the proportion of rapeseed cultivation areas from 2017 to 2021 in various suitability areas, we further validated the high reliability of the environmental suitability zoning results, which aligned closely with the actual conditions. During this period, the average distribution of rapeseed cultivation areas revealed that 86.84% were distributed in the optimum area, suitability area, and medium suitability area, while only an average of 2.55% of cultivation areas were found in the unsuitable zone (see Figure S6a). We hypothesized that areas with higher rapeseed cultivation frequencies corresponded to a higher suitability for rapeseed cultivation environments. To corroborate the credibility of the environmental suitability assessment results from different perspectives, we further examined the areas with rapeseed cultivation frequencies of 1, 2, 3, 4, and 5 within different environmental suitability areas and determined their respective proportions in the total cultivation area. The results indicated that as the cultivation frequency increased, a larger proportion of rapeseed cultivation areas was located within the optimum area, suitability area, and medium suitability area. Specifically, the proportion of areas with cultivation frequencies from 1 to 5 within these three zones was 85.46%, 90.48%, 88.48%, 90.48%, and 93.94%, respectively. Areas with a cultivation frequency of 5 constituted only 0.51% within the unsuitable zone. Therefore, our environmental suitability zoning results demonstrated a high level of credibility.

At the same time, it is necessary to acknowledge the uncertainties in this section of the research. Notably, not all rapeseed cultivation areas that existed from 2017 to 2021 fell within the categories of optimum area, suitability area, and medium suitability area. On average, approximately 2.55% of the areas were categorized as unsuitable area. There may be several factors contributing to this discrepancy. Firstly, despite the relatively high precision of the rapeseed cultivation dataset we utilized (with an average accuracy rate of 94.9% in China), factors such as atmospheric interference, unclear land cover boundaries, and the similarity between land cover types make it impossible to completely identify all existing rapeseed cultivation areas accurately. Therefore, the dataset we employed may have introduced some degree of influence on the validation of our environmental suitability results. Secondly, our study area spans over 117 thousand km^2, and due to constraints related to modeling and computational capacity, climate, topography, and soil dataset at a 1 km resolution were deemed more suitable as foundational data. Consequently, representing suitability for smaller, patch-level units may be a challenge. We employed 20m-resolution cultivation data to validate our environmental suitability analysis results, and due to differences in resolution, this may have also resulted in some smaller cultivation areas not falling within the suitable areas. Thirdly, the existing cultivation areas may not entirely represent the suitability for rapeseed cultivation. Some regions have only had rapeseed cultivation once in the past five years. The results of the suitability analysis serve to guide farmers in planting rapeseed in areas with higher suitability, thus increasing yield. Fourthly, determining the thresholds for zoning is also challenging to precisely ascertain, even though we employed a commonly used zoning approach in similar studies. Other potential factors contributing to these uncertainties include errors in model simulations and inaccuracies in the foundational dataset. Overall, our environmental suitability classification results demonstrate a relatively high level of credibility.



Supplementary Figure S7. Landscape visibility of farmland in study area.

Supplementary Questionnaire. Survey of tourists' landscape preferences and travel behavior.

Basic information

1. Your gender

☐Male ☐Female

2. Your age:_________

3. Your education level:

☐Junior high school and below ☐High school ☐Bachelor degree ☐Master degree and above

4. Your career

☐Public servant ☐Employee of a state-owned enterprise ☐Public institution personnel ☐Employee of a foreign company ☐Employee of a private company ☐Farmer/pastoralist ☐Freelancer ☐Full-time students ☐Others:_________

5. Your monthly income

☐Within RMB 2000 ☐RMB 2001-6000 ☐RMB 6001-10000 ☐Above RMB 10,001

6. Your marital status

☐Married ☐ Unmarried

7. Your family size:_________

8. Your city of residence:_________

Tourism behavior and landscape preference for rapeseed fields

1. Number of days expected to travel in Qinghai

☐7 days or less ☐8-14 days ☐15-21 days ☐22-28 days ☐28 days and above

2. Frequency of travel

☐1 time per week ☐1-3 times per month ☐2-6 times per year ☐1 time per year ☐1 time every 2 years or longer

3. Expected spending for the whole trip to Qinghai (personal spending)

☐Within RMB 2000 ☐RMB 2001-6000 ☐RMB 6001-10000 ☐Above RMB 10,001

4. I will make a special trip to see the rapeseed fields.

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree

5. Rapeseed flower fields make the natural scenic spots more beautiful.

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree

6. I prefer a whole rapeseed flower field to a fragmented one.

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree

7. I want to see creative patterns of rapeseed and other crops.

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree

8. I want to see rapeseed fields in many colors.

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree

9. I am willing to buy rapeseed production locally (rapeseed oil, etc.).

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree

10. I am willing to buy rapeseed production online.

☐Completely disagree ☐Disagree ☐No opinion ☐Agree ☐Completely agree