Quantitative analysis of the responses of boundary shifts in farming –pastoral ecotone of northern China to climate change

Wenjiao Shi*
Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
College of Resources and Environment, University of Chinese Academy of Sciences
Beijing, China
shiwj@lreis.ac.cn

Yiting Liu
Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
College of Resources and Environment, University of Chinese Academy of Sciences
Beijing, China
liuyitinggis@126.com

* Corresponding author: Wenjiao Shi, shiwj@lreis.ac.cn

***Abstract*—**Climate change can affect the shifts of farming-pastoral ecotone (FPE) boundaries, but previous studies have not adequately detected the climate contributions to the FPE boundary shifts. In this study, we presented gravity center analysis, boundary shifts detected in the X- and Y- coordinate direction and the direction of transects along the boundary, and spatial analysis to detect climate contributions at a 1-km scale in different ecological functional regions from the 1970s to the 2000s.Climate and land use data were used in this study. The results showed that during the 1970s–1980s and 1990s–2000s, the northeastern and southeastern parts of the FPE in northern China had similar spatial patterns with more extensive boundary shifts. In the directions of X-, Y-coordinate and the transects along boundaries, different ecological functional regions had significant differences in climate contributions to FPE boundary shifts during the three periods. In addition, during most of the periods, the results in different directions had good agreement in most of the ecological functional regions. However, the values of contributions in the directions of transects in the X- and Y-coordinate directions (4–56%) were always larger than those in the direction of transects along boundaries (1–17%), which shows that the results in the transect directions are more reliable and stable. Thus, the method of detecting the shifts in the transect directions developed by this study is an alternative one for analyzing the climate contributions to boundary shifts. Further evidences for explanation of the driving forces of climate change were given by spatial analysis of the relationship between climate change and land use change in the context of the FPE boundary shifts in northern China. Our findings provide an improved understanding of the responses of boundary shifts in farming–pastoral ecotone of northern China to climate change, which will be important for addressing adaptation and mitigation measures to climate change and regional land use management.

Keywords*—contributions, boundary shift, farming-pastoral ecotone, climate change, land use*

I. INTRODUCTION

The farming-pastoral ecotone (FPE) is a transitional region between cropland and pasture, which is sensitive to both climate change and human activities [1]. Hence, the cropland and the grassland in this region transformed from each other continually [2]. As the FPE in Northern China had the largest extent among all of the FPEs in China and worse natural environment, it became a hot spot in the field of climate change and land use change, concentrating on boundary fluctuation of the FPE. Some previous studies showed the moving directions of the climate and land use boundaries were opposite in Northern China [3, 4]. Meanwhile, the land use and land cover change were controlled by both policies and cropland reclamation, which led to the fluctuations of boundaries [3]. More researchers have studied the response of land use change to climate change and human activities quantitatively [4]. The models such as the Conversion of Land Use and its Effects Model (CLUE) [5] and Environment for Geoprocessing Objects Model (Dinamica EGO) [6] were applied in detecting the impacts of climate change and human activities on the land use change in the FPE of Northern China, and these models were often combined with economic models [7]. Although models can provide more information on mechanism aspect, the application of these models was limited to the sophisticated operation, parameter acquisition and inconsistent validation. More precise results of the specific climate factor impacts on the land use change in the FPE of northern China can be given by mathematical statistics methods, such as logistic regression [5] and pearson correlation [8]. Most of the previous studies detected the impact of climate on land use change at point [9, 10] and polygon levels [11, 12]. However, the methods for analyzing quantitative responses of boundary shift of the FPE in northern China to climate change are still unclear, especially in line level [1, 9]. In addition, previous studies used the whole study area as a study unit, which may lead to the neglect of the spatial heterogeneity in the analysis.

Based on the delineation of climate and land use boundaries of the FPE in northern China, we analyzed the shift of the FPE in point, line and face level, and calculated

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the contribution of climate change to the shift of FPE in the X- and Y-coordinate direction and in the direction of transects along the boundaries.

II. DATA AND MTHOD

A. Study area

The study area (102°40′E-126°14′E and 34°16′N-48°57′N) lies in arid and semi-arid area of China and is also a transitional region between cropland and pasture [13], covering ten provinces autonomous regions or metropolises: Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Beijing, Shanxi, Shaanxi, Ningxia and Gansu (Fig. 1).

In order to recognize the spatial heterogeneity of the contributions of climate change to the boundary shifts in the FPE of northern China, we divided the study area to eight ecological functional regions based on their ecosystem services [14]. The regions were the northwest (NW-1) and the southeast (SE-1) cropland areas on the southeastern fringe of the Greater Hinggan Mountains, the northwest (NW-2) and southeast (SE-2) agricultural-forestry-pastoral production regions on the southeast fringe of the Inner Mongolian Plateau, the northwest (NW-3) and the southeast (SE-3) farming-pastoral regions on the northern Loess Plateau, and the northwest (NW-4) and southeast (SE-4) arid desert-oasis cultivated regions in the Hexi Corridor (Fig. 1).

B. Data

The climate data including daily temperature and precipitation during 1970-2010 were obtained from 197 national meteorological stations (Fig. 1). Using the Multiple Analysis of Series for Homogenization (MASH) software package, the homogenized daily mean temperature series were created without systematic bias from time and instruments of observation [15]. Meanwhile, the precipitation, the active accumulated temperatures ≥10 °C (AAT10) and the trend of the two indices at each national meteorological station of different period (1970s-1980s, 1980s-1990s, 1990s-2000s) were calculated based on the method of our previous study [12].

The land use data were from the National Land Cover Dataset (NLCD), which contained cropland, grassland, forest, water body, built-up land and unused land for the past 40 years [16].

C. Delineation of FPE boundaries based on both climate and land use data

The study used the FPE boundaries of 1970s, 1980s, 1990s and 2000s in northern China based on both climate and land use data. The climate boundary was defined by two conditions: (i) the acidity index was between 0.2 and 0.5, with precipitation variability between 15% and 30%; (ii) the 400mm isotype located in the central of the boundary, and the 300mm and 500mm isotypes delimited the northwest and southeast boundary, respectively. The land use boundary should also satisfy two conditions: (i) the area-percentages of both cropland and grassland must be greater than 15% in each 1 km×1 km grid; (ii) the sum of cropland area-percentage and grassland area-percentage should be greater than 50% [17].

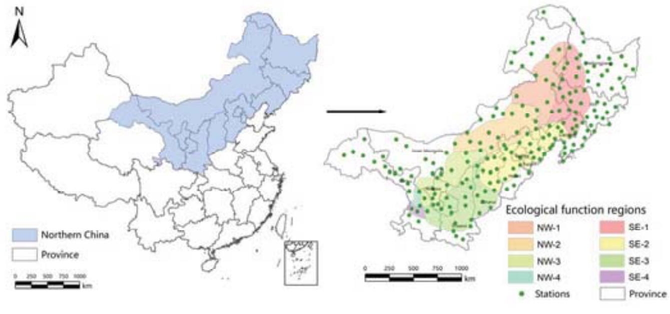

Fig. 1. The location of the FPE in northern China (left) and the distribution of meteorological stations and ecological function regions (right).

D. Gravity center shifts of the FPE

The tool named "feature to points" in ArcGIS 10.3 was used to obtain the gravity centers of each ecological function region during 1970s, 1980s, 1990s and 2000s. Meanwhile, the Euclidean distance and moving directions were calculated in different periods for the gravity centers.

E. Shifts of coordinates in the X- and Y-coordinate directions of the FPE

To detect the moving distance and direction in the X- and Y-coordinate directions of the FPE, a 1 km × 1 km fishnet was generated by ArcGIS 10.3 in the ecological function regions. In the X-coordinate direction, the line number became larger from south to north, and in the Y- coordinate direction, it increased from west to east. The FPE boundaries of different periods intersected the lines in the X- and Y-coordinate directions, and the distance between intersection points of climate boundaries (Cd_{ep_lp}) or land use boundaries (Ld_{ep_lp}) was calculated. Meanwhile, we defined the moving direction (*Direction*) as 1 (-1) if the FPF boundaries in later period moved eastward (westward) or northward (southward), and 0 with no changes. Hence, we can gathered the moving distance of climate boundaries (ΔCd_{ep_lp}) and land use boundaries (ΔLd_{ep_lp}) in each line of X- and Y-direction by (1) and (2):

$$\Delta Cd_{ep\_lp} = Cd_{ep\_lp} \times Direction \tag{1}$$

$$\Delta Ld_{ep\_lp} = Ld_{ep\_lp} \times Direction \tag{2}$$

Where *ep* is the earlier period, *lp* is the later period.

F. The FPE boundary shifts in the direction of transects along the boundaries

We used the Digital Shoreline Analysis System (DSAS) [18, 19], which provided by the U.S. Geological Survey to detect the FPE boundary shifts in the direction of transects along the boundaries. By modifying the buffer of innermost FPE boundary manually, the baseline segments were generated which had no intersection points with any of the FPE boundaries. Then the baseline segments were put into the DSAS, and the lines with a 1 km interval were generated perpendicularly from the start of the baseline. The length from the baseline to the intersection points of climate or land use boundary in different period was calculated in each transect. Hence, we gathered the moving distance and direction of climate boundary and land use boundary using (3) and (4):

$$\Delta Cd_{ep\_lp} = Cd_{lp} - Cd_{ep} \tag{3}$$

$$\Delta Ld_{ep\_lp} = Ld_{lp} - Ld_{ep} \tag{4}$$

Where *ep* is the earlier period, *lp* is the later period, ΔCd_{ep_lp} (ΔLd_{ep_lp}) is the moving distance of climate boundary (land use) boundary in each transect, Cd_{ep} (Ld_{lp}) and Cd_{lp} (Ld_{ep}) are the length from the baseline to the intersection points of climate (land use) boundary in earlier and later period, respectively.

G. *Identification of the climate contributions on FPE boundary shifts*

To identify the climate contributions on the FPE boundary shifts during 1970s-1980s, 1980s-1990s and 1990s-2000s, the correlation analysis was applied for the moving distances of climate boundaries (ΔCd_{ep_lp}) and land use boundaries (ΔLd_{ep_lp}) in the X- and Y-coordinate directions and in the direction of transects along the boundaries in different ecological function regions. If the correction is positive and significant ($r>0$ and $p<0.05$), we considered the shift of land use boundary was affected by the shift of climate boundary significantly and used the coefficient (r^2) to indicate the climate contributions on the FPE boundary shifts.

III. Results

A. *Gravity center shifts in the FPE boundary in northern China*

The gravity center of climate boundaries showed various moving trends in different ecological function regions (two parts: northwest (NW) part and southeast (SE) part; four regions: region 1, region 2, region 3 and region 4) during 1970s-1980s, 1980s-1990s and 1990s-2000s (Fig. 2). The shift of climate boundaries in the SE part of the FPE was larger than those in the NW part during the three periods, with the average shift distance of 54.0 km and 24.3 km, respectively. Meanwhile, the shift range decreased from the northeast to the northwest, with the average shift distance of 63.2 km in the region 1 and 12.1 km in the region 4, respectively. During 1970s-1980s, the gravity center in region 1, NW-3 and SE-2 both moved southward, which was highly relative to the increasing of precipitation in these areas, and the largest average moving distance was occurred in this period (51.2 km).

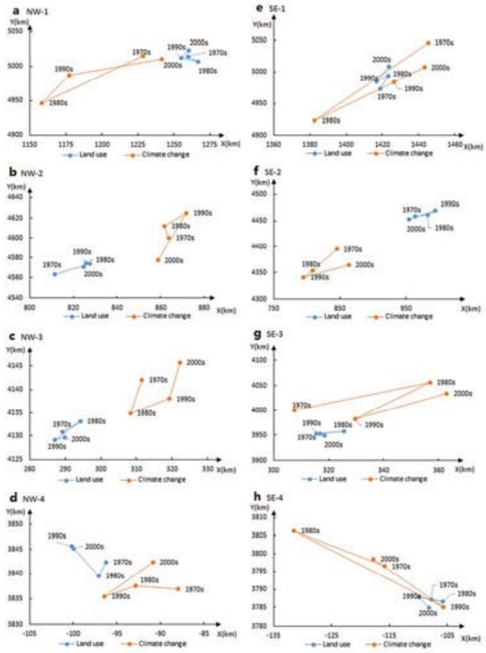

Fig. 2. The gravity center of FPE boundary shifts based on climate change in each ecological functional region during the 1970s–1980s, 1980s–1990s and 1990s–2000s

The gravity center of land use boundaries had slighter shift than climate boundaries. Similar to climate boundaries, shifts of the land use boundaries were more extensive in the SE than the NW part of the FPE, with the average shift distance of 14.0 km and 7.3 km, respectively. Region 1 and region 2 had more extensive average shift distances (17.3 km, 15.8 km) than region 3 and region 4 (6.0 km, 3.4 km) during the three periods. The gravity center of land use boundaries showed larger shift during 1970s-1980s and 1990s-2000s than those during 1980s-1990s, with the average moving distance of 11.4 km, 11.8 km, and 8.6 km, respectively. However, the largest shift was 42.7 km, moving northeastward occurred in the SE-2 during 1990s-2000s among different regions and periods. In addition, the gravity centers in most of the regions moved eastward during 1970s-1980s (except for NW-4), west during 1980s-1990s (except for SE-2) and various during 1990s-2000s.

B. *Coordinate shifts in the X- and Y-coodinate directions*

Coordinate shifts of both climate boundaries and land use boundaries in the X- and Y-coordinate directions had similar moving trend to the shifts of the gravity center that the moving distance decreased from the northeast (region 1 and 2) to the northwest (region 3 and 4). For climate boundaries, The greatest shifts occurred in SE-2 during 1990s-2000s in the X-coordinate direction (Fig. 3e), in NW-1 during 1970s-1980s in the Y-coordinate direction (Fig. 3b), with the largest shift distance of 278.5 km and 271.3 km, respectively. In region 1, NW-3 and SE-2, the boundaries shifted southward during the 1970s-1980s, and moved northward during the later period.

For land use boundaries, coordinate shifts in the X- and Y-coordinate directions were less than those of climate

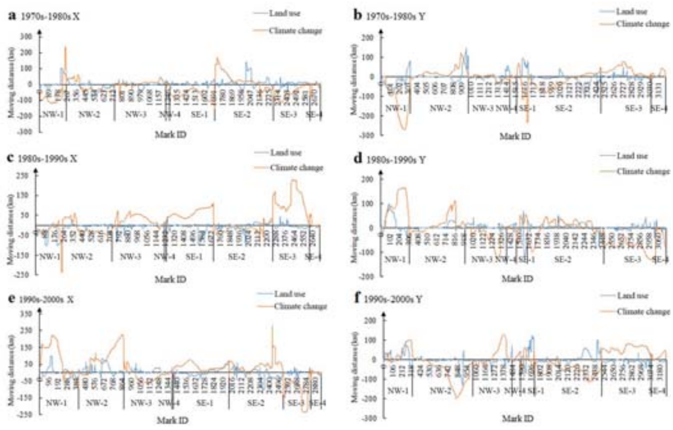

Fig. 3. Changes of climate and land use boundaries detected at coordinates in the X- and Y-directions

boundaries. The most extensive shift distance (140.4 km) was observed in SE-2 during 1970s–1980s in the X-coordinate direction shifting eastward (Fig. 3a), and 149.8km in NW-2 during 1980s-1990s in the Y-coordinate direction moving northward (Fig. 3d).

C. Shifts in the directions of transects along the boundaries

Region 1 and region 2 had more extensive shifts of climate boundaries than other regions, especially during 1970s-1980s in regions 1, with the average moving distance of 98.4 km in NW-1 and 129.8 km in SE-1, respectively. Similar to the detection in X- and Y-coordinate directions, the climate boundaries shifted southward during 1970s-1980s and shifted northward during 1980s-1990s in NW-1, SE-1, NW-3 and SE-2 (Fig. 4).

The shifts of land use boundaries were slighter than climate boundaries. For land use boundaries, region 1 had more extensive shifts than those in other regions, with 135.5–182.8 km shift distance in NW-1 and 163.3–217.8 km shift distance in SE-1. Region 4 had the slightest shift during different periods, with a 4.4 km average moving distance. During the 1970s-1980s, the southward shifts were observed in most of the study areas, and land use boundaries moved northward during 1980s-1990s (Fig. 4d). Meanwhile, the most extensive shift occurred in SE-1 during 1990-2000s, with the largest shift distance of 217.8 km moving northeastward.

D. The climate contributions to the FPE boundary shifts in the X- and Y- coordinate direction

In region 1, significant relationships in the X-coordinate direction between the shifts of climate boundary and land use boundary were observed during 1970s-1980s, 1980s-1990s and 1990s-2000s only in NW-1, with the climate contribution of 44.4%, 10.7% and 20.2%, respectively. In the Y-coordinate direction, only the FPE boundaries in NW-1 during 1990s-2000s affected by climate change significantly, with 4.7% of climate contribution. No climate contribution was observed in SE-1 during different periods.

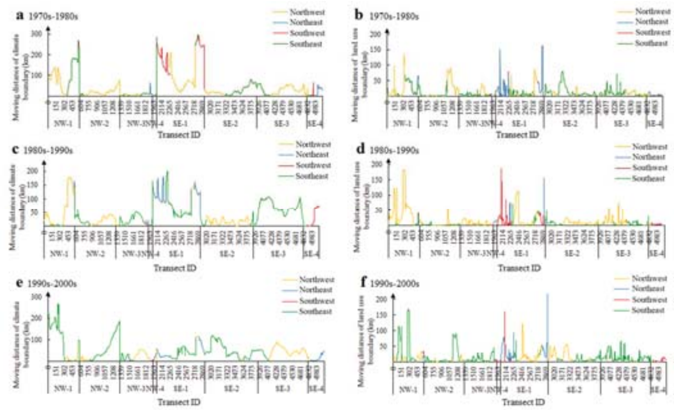

Fig. 4. Changes of climate and land use boundaries detected in the directions of transects along the boundaries

In NW-2, significant effects of climate were found in both the X-coordinate direction and Y-coordinate direction during 1970s-1980s, with the contribution of 20.9% and 8.8%. During the 1980s-1990s and 1990s-2000s, the climate change only had significant effects in the Y-coordinate direction, and the climate contribution to the shift of the FPE were 55.9% and 10.4%, respectively. In SE-2, climate contribution was only found during 1980s-1990s in the X-coordinate direction (4.0%).

In NW-3, 8.2% of the FPE shifts were relative to climate change during 1980s-1990s in the Y-coordinate direction, and no significant effect of climate change was found during other periods or in the X-coordinate direction. In the SE-3, only 20.1% and 22.7% of the climate change contribution were found in the X- and Y-coordinate direction, respectively. In region 4, significant effect of climate change on the shift of the FPE was observed in NW-4 in the Y-coordinate direction, and the climate contribution was 5.2%. In region 3 and region 4, climate change effects on the shift of the FPE were slighter than those in region 1 and region 2, which indicated that anthropogenic factors were the mainly causes driving the shifts of the FPE.

E. The climate contributions to the FPE boundary shifts in the directions of transects along the boundaries

In the directions of transects along the boundaries, climate had similar contributions to those in the X- and Y-coordinate directions.

In NW-1, 2.7% and 1.1% of the FPE shift were relative to the climate change during 1970s-1980s and 1990s-2000s, respectively. In SE-1, only during 1990s-2000s, climate effects was found, with 1.5% of the climate contribution. In NW-2, climate contributions of 16.8% and 4.3% were observed during 1970s-1980s and 1990s-2000s, and caused the northwestward and southeastward shift of the FPE, respectively. In SE-2, 3.2% of the shifts were attributed to climate change, which led a northwest shift of the FPE in this area. In NW-3, the FPE shifted southeastward due to a 4.3% climate contribution during 1980s-1990s. In SE-3, climate led a northwest shift of the FPE during 1970s-1980s, and a southeast shift in the north part of the FPE during 1990s-

TABLE I. THE QUANTITATIVE DETECTION OF CLIMATE CHANGE EFFECTS ON THE BOUNDARY FLUCTUATION IN THE FPE OF NORTHERN CHINA

Regions	Periods	X direction	Y direction	Transect direction
NW-1	1970s-1980s	0.444	—	0.027
	1980s-1990s	0.107	—	—
	1990s-2000s	0.202	0.047	0.011
NW-2	1970s-1980s	0.209	0.088	0.168
	1980s-1990s	—	0.559	—
	1990s-2000s	—	0.104	0.043
NW-3	1970s-1980s	—	—	—
	1980s-1990s	—	0.082	0.043
	1990s-2000s	—	—	—
NW-4	1970s-1980s	—	0.052	0.153
	1980s-1990s	—	—	—
	1990s-2000s	—	—	—
SE-1	1970s-1980s	—	—	—
	1980s-1990s	—	—	—
	1990s-2000s	—	—	0.015
SE-2	1970s-1980s	—	—	—
	1980s-1990s	0.04	—	0.032
	1990s-2000s	—	—	—
SE-3	1970s-1980s	0.201	0.227	0.099
	1980s-1990s	—	—	—
	1990s-2000s	—	—	0.019
SE-4	1970s-1980s	—	—	—
	1980s-1990s	—	—	—
	1990s-2000s	—	—	—

2000s, with a 9.9% and 1.9% of the climate contribution. In region 4, the significant effect of climate on the shift of the FPE was only found in NW-4 during 1970s-1980s, which indicated the shifts of the FPE were mainly driven by human activities in region 4, especially in the SE-4 and during 1980s-2000s.

F. Spatial analysis of the driving forces of climate change in land use change regions

The shifts of the FPE boundaries were driven by both climate change and anthropogenic factors. The warmer and wetter climate promoted the cropland reclamation, such as in the Northeast China, and the increasing cropland was relative to the warmer climate change which attributed to the shift of the FPE in region 1 (Fig. 5). In addition, anthropogenic factors is another important factor that affects FPE shifting in northern China. Since 1998, the Grain for Green Project was practiced in NW-2 and NW-3, more cropland in these regions converted to grassland which led to a narrower FPE boundaries during 1990s-2000s (Fig. 5c).

IV. DISCUSSION

A. Comparisons of the FPE shifts in northern China in previous studies

Previous studies showed the warmer climate accelerated the reclamation of cropland since 1980s in the Northeast of China, and it was consist with the result that the FPE shifts in NW-1 and NW-2 were affected by climate significantly [20-22]. Some researchers presented that the northeast part and the north part of the FPE boundary had greater shift than the northwest part. We also found same results in gravity center analysis that the average moving distance was lager in the northeast and smaller in the southwest [23]. Meanwhile,

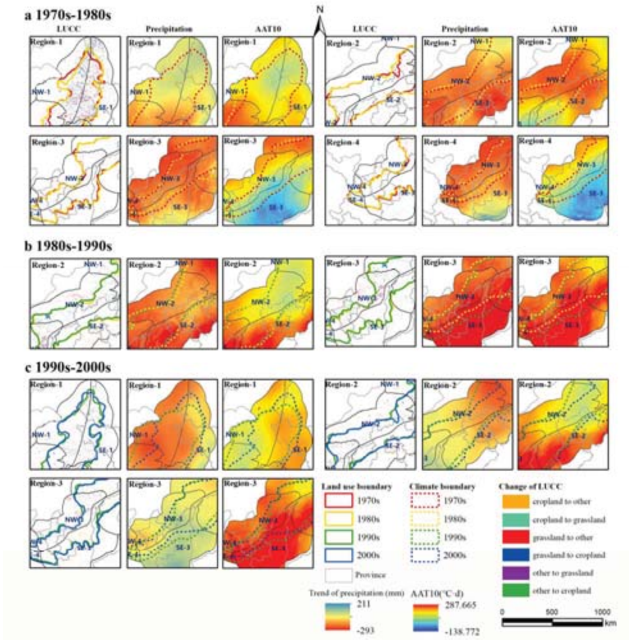

Fig. 5. The spatial analysis of land use change in response to climate change in the FPE of northern China.

some studies also found the northwest part of the FPE shifted mainly caused by the Grain for Green Project since 1998 significantly [24] and the land use change was driven by human activities after 1980s [25]. We also found insignificant effect of climate to the shift of the FPE in the northwest of China.

B. The comparison of results from different methods

The detection in the X- and Y-coordinate directions provided a quick and easy method to study the climate contribution in a large scale. The detection in the directions of transects along the boundaries was more accurate and suit for the precise detection at small scale [17, 26]. Meanwhile, the detection in different levels had similar results. Such as the climate boundaries shifts were greater than the land use boundaries, and the FPE boundaries in region 1 shifted most extensive, in region 4 shifted slightest. During 1970s-1980s, the boundary in NW-1, SE-1, NW-3 and SE-2 all shifted southward, and then northward after this period. Similar to climate boundaries, land use boundaries in most of regions shifted southward during 1970s–1980s, and then moved westward during 1980s–1990s. The shifts of FPE were significantly relative to the climate change in NW-1, SE-1, NW-2, NW-3 and SE-2 by all of detection methods.

C. Study limitations

This study provided methods to detect the climate contribution to the shift of the FPE in different regions and periods. However, there were uncertainties in the junction between different parts of ecological function regions when computing the climate contributions. Meanwhile, the quantitative detection of the anthropogenic factors (such as public policy, farmer decisions) need to be studied in the future studies.

V. CONCLUSION

This study revealed the spatially explicit contributions of climate change to the FPE boundaries in different ecological function regions of Northern China. The shifts of the FPE boundaries were driven by both climate change and anthropogenic factors. The shift of climate boundaries was greater than the land use boundaries due to the lag effect of the climate. Meanwhile, the land use boundaries shifted frequency and varied between segments, which presented the anthropogenic factors droved the moving of the FPE mainly. The climate contributions to FPE boundary shifts in different ecological regions of northern China were different during the three study periods. The climate contributions in region 3 and region 4 were less than those in region 1 and region 2 due to the human activities (such as the Grain for Green Project) in the northwest of China during 1990s-2000s. In addition, human activities had more impact on the NW part of the FPE than the SE part during the three periods. Hence, targeted mitigation measures to climate change and regional land use management should be practiced to adapt to climate change and insure food security.

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