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Regional shifts of crop species diversity in rainfed and irrigated cultivation in Iran

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ABSTRACT

Concerns about the negative effects of declining agricultural biodiversity due to modern agricultural practices and climatic constraints in various parts of the world, including Iran, on the sustainability of agricultural ecosystems are increasingly growing. However, the historical knowledge of temporal and spatial biodiversity is lacking. To identify the value and trend of crop diversity in Iran was used biodiversity indices based on the area under rainfed and irrigated crops and total from 1991 to 2018. The crop species diversity of irrigated cultivation was higher than the rainfed and total cultivations area. The Shannon and Simpson indices had experienced a constant trend, but species richness was increased, which was related to the rise in the area of some species in recent years. The area of wheat and barley had a significant impact on crop diversity so that Shannon diversity was reduced with their dominance. Overall, this study revealed that Iran's agricultural system relies on wheat and barley. We warn that by increasing the area of these crops and the prevalence of monoculture, the probability of damages increased due to external factors such as sudden weather changes or the spread of diseases and the important consequences of which will be instability and production risk in the future.

Introduction

The production of food, feed, fiber and fuel for a growing population is a major challenge¹ for which climate change can have negative consequences on their production. A rational and cost-effective approach in these circumstances may be to create flexibility in agricultural systems by increasing biodiversity². To illustrate, in the agricultural ecosystem, when precipitation is limited, crop diversity can function as a catalyzer to agricultural production². Actually, diverse agroecosystems with higher resilience to climate change³ and different types of risks⁴ will continue to produce more nutritious and healthy food and provide ecosystem services⁵⁻⁷. This means that diversification of crops increases the ability of agroecosystems and provides protection against the variability of environmental as different crops react to change differently³. In addition, diversification in the agroecosystem causes an increase in the efficiency and productivity of resources and decreases risk^{8,9}.

Biodiversity is related to vital ecological processes such as nutrient and water cycles, pest management, and disease control in agroecosystems⁵⁻¹⁰, which contributes to the determination of the quantity, quality, and reliability of ecosystem services^{11,12}. Recent investigation indicates that diversification of agricultural ecosystems provides many advantages such as increasing crop yield, pollinators, carbon sequestration, weed and pest suppression, etc. ^{2,13-18}. Also, crop diversity has a significant effect on the stability and sustainability of crop production^{19,20}. The most traditional form of agricultural activity prevalent in many Asian countries and some tropical regions was to increase crop diversity by intercropping²¹⁻²³. In addition to reducing diseases and pests than monoculture with this method, they also minimized soil erosion in various cropping systems with more intense and extensive soil cover^{24,25}.

Agricultural biodiversity at various levels of organization such as ecosystems, crops, species and genes may not change in one direction under effect of different processes. In addition, since the beginning of the 20th century, crop genetic diversity has also gradually declined in the agroecosystems of developed countries^{26,27}. This is largely attributed to the systematic substitution of genetically diverse traditional varieties by homogeneous new varieties ²⁸, leading to reduced genetic variation, both within and between varieties, in the fields²⁹. Present agricultural approaches may have reduced the biodiversity of agroecosystems³⁰. In contrast to multiple cropping, agricultural intensification, mechanization, specialization and increase in the size of field declines landscape-level agricultural diversity^{31,32}.

On a global scale, crop diversity changes linearly increased in recent decades, that this increase was associated with agricultural economies and global diets. In particular, structural adjustment and

agricultural trade liberalization programs in the 1980s have led to the production and export of several selected crops or genotypes, which has a major impact on crop selection and management at the regional or country-level, especially in developing countries³³. In recent decades, patterns of crop diversity change are expected to vary in different regions due to climatic constraints for crop growth. For example, cropping systems in Iran are based on wheat and rice, that the rice-based system is limited to land near the Caspian Sea, and the wheat-based system is dominant in other regions of Iran. The dominance of wheat and rice in these regions has caused reduce crop diversity^{34,35}.

But how the diversity of crop species in Iran has changed in recent times? Here, to answer this question, we have used the data of the area under cultivation from 1991 to 2018 to recognize the value and trend of crop diversity. It was hypothesized that (1) Crop diversity has changed in different latitude and longitude; (2) The pattern of crop diversity changes has been affected by environmental conditions, especially water availability; (3) The pattern of crop diversity has changed over time.

Results

Fluctuations in the area under cultivation. The results of this study showed that the crop area increased by 3.2%, from 10.7 million ha in 1983 to 11.1 million ha in 2018. However, the highest crop area of about 13.1 million hectares in this period was in the years 2005 to 2007 (Fig. 2a). Wheat was the predominant crop in this period, with the area under cultivation of more than 6 million ha in most years, except for two periods. The first and second negative peak occurred from 1999 to 2001 and 2008 that both of them were also very evident in the whole area under cultivation. The predominant crop was followed by barley, alfalfa and rice. Up to 1990, the rate of increase for barley area was 0.101 million ha year⁻¹ but after that it was decreased to 0.164 million ha year⁻¹. Although the growth rate for alfalfa and rice was 0.004 and 0.003 million ha year⁻¹, their area was not significant compared to the area of wheat and barley (Fig. 2a).

Most areas under rainfed cultivation belonged to two crops, wheat and barley (Fig. 2b). In the area under rainfed cultivation, the trend of changes in total crops and wheat (Fig. 2b) was similar to the whole area under cultivation (Fig. 2a), which shows the high impact of fluctuations in the area under dryland wheat cultivation on the whole area under cultivation.

In the area under irrigated cultivation, the predominant crop (wheat) was followed by barley, alfalfa and rice (Fig. 2c). The barley area was 0.69 million ha in most years, except for one period. The positive peak occurred from 1987 to 1991. The growth rate of alfalfa and rice was 0.005 and 0.003 million ha year⁻¹. The area under irrigated cultivation increased by 21.7%, from 4.8 million ha in 1983 to 5.9 million ha in 2018 (Fig. 2c). The predominant crop (wheat) was followed by barley, alfalfa and rice.

Shannon diversity index. The average Shannon diversity index of all sites (irrigated and rainfed cultivation) was 1.32 during 1991-2018 in the study area. The highest and lowest values were observed in Shahroud (2.19±0.2) and Bijar (0.5±0.1), respectively (Fig. 3a and b). The Shannon index's positive and negative trends were significant ($p \leq 0.05$) in approximately 18% and 30% of sites, respectively (Fig. 3b). The highest increase and decrease of Shannon index slope were achieved in Birjand (0.04) and Rasht (-0.05), respectively. The Shannon index was in the range of 0.14 to 2.34 with an average of 1.42 in 2018, which was an improvement over the long-term average (Fig. 3a and b).

The value of Shannon diversity index for the country's rainfed cultivation was in the range of 0-1.54 with an average of 0.61 during 1991-2018. The highest Shannon index was for Sari (1.54±0.3). The Shannon index for nine sites was zero due to the lack of cultivation of rainfed crops (Fig. 3d). Also, the detected trend of Shannon index was negative for 59.7% (for 29.9% of which were significant) of sites and positive for 26.9% (for 9% of which were significant) of sites, respectively (Fig. 3d). The low percentage of sites with a positive trend indicates the declining situation of crop diversity rainfed cultivation. On the other hand, the value of Shannon index was between zero and 1.39 with an average of 0.6 in 2018, which shows a reduction in crop diversity compared to the long-term average (Fig. 3c). The highest Shannon index was found for Bojnourd (1.39±0.2) followed by Sari (1.270.3±) in 2018. All 14 sites with Shannon diversity index equal to zero (due to lack of rainfed cultivation) were located in the South, Southeast and Center part of the country (Fig. 3c and d).

The long-term average of Shannon index for irrigated cultivation was 1.4. The highest and lowest crop diversity was observed in Shahroud (2.15±0.2) and Babol (0.12±0.3) during 1991-2018, which indicates a better situation under irrigated conditions than rainfed conditions (Fig. 3f). Also, the trend of crop diversity was positive for 61.2% (for 35.8% of which were significant) of sites and negative for 38.8% (for 10.4% of which were significant) of sites, respectively. The highest increasing and decreasing trend was related to Izeh (with a slope of 0.04 year⁻¹) and Bandar Abbas (with a slope of -0.04 year⁻¹), respectively (Fig. 3f). In 2018, the highest and lowest values of Shannon index were observed in Jiroft (2.34±0.2) and Rasht

(0.64 ± 0.2), respectively (Fig. 3e). The average of Shannon index in 2018 (1.57) was increased by about 11.35% compared to the long-term average (Fig. 3e and f).

Simpson index. The average Simpson diversity index of all sites (irrigated and rainfed cultivation) ranged from 0.21 to 0.83 (Country average: 0.6) (Fig. 4b). Simpson index shows the evenness of the area under cultivation of the species. The highest and lowest Simpson index, which indicates uniformity and non-uniformity of the area under cultivation of the species, were observed in Jiroft (0.83 ± 0.06) and Bijar (0.21 ± 0.06). This result shows the suitable situation of Jiroft in terms of diversity and evenness of the species. It should be noted that the slope of Simpson index changes was negligible during the study period (Fig. 4b). The results for 2018 showed that the values of Simpson index were between 0.05 and 0.88 (country average: 0.63). This index's highest and lowest values were also observed in Jiroft and Rasht (Fig. 4a).

In rainfed cultivation, the average Simpson index was 0.53 (Fig. 4d). The maximum and minimum values of this index were observed in Hajiabad (0.97) and Saveh (0.12). During the same period, the Simpson index trend in 44.8 (14.9% of which were significant) and 52.2% (14.9% of which were significant) of the sites was increasing and decreasing, respectively, which indicates an increase in species evenness (area cultivation). The highest increasing slope of Simpson index was obtained in Bandar Abbas (0.023) and the highest decreasing slope was obtained in Rasht (-0.015) (Fig. 4d). On the other hand, in 2018, the average, maximum and minimum of Simpson index were equal to 0.68, 1 (Isfahan and Yazd) and zero (Semnan and Kerman), respectively, which indicates an increase in Simpson index compared to the long-term average (Fig. 4c and d).

In irrigated cultivation, the Simpson index was 0.64 (Fig. 4f). This index's highest and lowest values were obtained from Jiroft (0.83) and Babol (0.13) during the same period, which respectively showed the similar area under cultivation of species in Jiroft and the dominance of some species such as rice in Babol. The trend of Simpson changes was such that 35.8% and 13.4% of the sites had a significant increase and decrease, respectively, which indicates an increase in evenness of cultivation area (Fig. 4f). In 2018, the Simpson index values were in the range of 0.3-0.88 with an average of 0.7, which increased compared to the long-term average; in other words, some species' dominance was reduced (Fig. 4e and f). The highest and lowest values were obtained from Jiroft (0.88 ± 0.06) and Sari (0.3 ± 0.16) (Fig. 4e).

Species Richness. Investigation of species richness index in both cultivation patterns of Iran (rainfed and irrigated cultivation) showed that an average of species richness was about 13.2 species (Fig. 5b). The highest number of species was observed in Isfahan (19.6 ± 2.1), which is affected by the number of species cultivated under irrigated (Fig. 5b and f). In 2018, the species richness was increased by about 22.7 % compared to the long-term average due to increasing the number of species. Also, investigation of the species richness index showed that 85.1% of sites had an increasing trend (59.7% of which were significant), which indicates an increase in the number of species (Fig. 5a and b). Moreover, there was a significant difference ($p < 0.01$) between the average species richness under irrigated (12.5) and rainfed cultivation (3.7) (Fig. 5d and f). In 2018, the number of irrigated and rainfed species was 15.3 and 3.8, respectively, showing the more suitable situation under irrigated cultivation (Fig. 5c, d, e and f).

Correlation of indices. The relationship among Shannon, Simpson and species richness indices was plotted with different regression equations in Fig. 6. Each point in each Figure represents the value of index for each site and each year. There was a significant polynomial regression ($r = 0.95^{**}$) between the Shannon and Simpson indices indicating that by increasing each index, the value of other index was also increased (Fig. 6a). The Shannon index increased with increasing species uniformity. Since the sites with higher species richness were above the regression line, it can be concluded that increasing the species richness along with the Simpson index leads to increasing Shannon index with a greater slope compared to lower species richness (Fig. 6a).

As shown in Fig. 6b, high species richness does not necessarily increase Shannon index. The pattern of point distribution in Fig. 6b is almost similar to the shape of an almond. Sites with a lower Simpson value (smaller circles) are located on the almond's lower edge. So, increasing species richness without increasing evenness does not increase Shannon index. Also, the lowest range of changes in Shannon index was obtained in the conditions of increasing species richness (the end of the almond). If high species richness coincides with the evenness of the species, it can increase Shannon index. Shannon index also had a positive and significant correlation ($r=0.47^{**}$) with species richness (Fig. 6b). The results of the relationship between Simpson index and species richness ($r=0.31^{**}$) showed that by increasing the number of species, Simpson index was somewhat increased, but Simpson index actually indicates the evenness of species in terms of cultivated area and is more affected by the area under cultivation of species (Fig. 6c).

Correlation between the diversity index and the area under cultivation of wheat and barley. Generally, by increasing the area of wheat and barley, Shannon index was reduced (Fig. 7). The relationship between the area of wheat and Shannon index was a significant decrease ($r = 0.51^{**}$ and slope = -0.41) in the whole country (Fig. 7c). Also, there was no significant decrease between the area of barley and Shannon index ($r = 0.34$ and slope = -0.08) (Fig. 7d). Given that the Shannon index is calculated based on the number and cultivation area of species, as long as the species has an equal cultivation area, the Shannon index increases. Therefore, by increasing the area of wheat and barley due to the dominance, crop diversity was reduced (Fig. 7). Investigation of the area of the dominant crops in the period showed that crop diversity indices were greatly affected by the area of wheat and barley. As the cultivated area of crops increases or reduces, crop diversity indices also fluctuate. The Shannon index was decreased when the dominance of wheat and barley increased per year due to a significant difference between their area under cultivation compared to other crops (Fig. 7).

Investigation of species showed that some species such as wheat, barley, alfalfa, beans, potato, rapeseed, corn, lentils, onion, pea, cucumber, tomato and watermelon had been cultivated in more than 90% of the study areas. Other crops such as sugarcane, flax and hemp were present in less than 10% of the study areas. Flax and hemp were present only in Sari (Fig. 8).

Trend of indices. Considering Shannon's value during 1991-2018, the general trend of crop diversity had a non-significantly increase ($r = 0.16$ and Slope = 0.001) (Fig. 9a). The highest and lowest Shannon indices were observed in 1999 (1.45) and 1994 (1.2), respectively. Also, the change-points in the trend of Shannon index were observed in 1999 and 2010. The Shannon index had a decreasing trend between 1999 and 2010 with a slope of -0.01. After that, it started an increasing trend until 2018 with a slope of -0.03 (Fig. 9a). The trend of Simpson index was almost similar to Shannon index, except that the slope of the line was almost constant for Simpson index (Fig. 9b). Moreover, the species richness index trend in the last three decades was different from the other indices. The species richness was a significant positive trend ($r=0.84^{**}$) with a slope of 0.15 (Fig. 9c).

Discussion

Result of this study shows that crop diversity in Iran is associated with and affected by some biotic and abiotic factors. Climate is one of the factors affecting and determining biodiversity in many parts of the world. In Iran, according to the study results, crop diversity has been affected by climate, in such a manner that reducing diversity in rainfed cultivation was much less than irrigated cultivation due to the lack of water for the cultivation of many crops. Due to low average annual precipitation and the non-uniformity of annual its distribution in Iran^{36,37}, only crops such as wheat, barley and pea are grown in rainfed cultivation, while in irrigated cultivation, there is more crop diversity. Generally, the average annual precipitation was low in Iran except in the northern regions, which significantly impacted rainfed crops' diversity. As shown, water-limited regions such as Iran, which has temporally and geographically uneven distribution, are mostly affected by climate changes and its changes (such as precipitation and temperature fluctuations) on the output of the agricultural sector^{36,38-40}. Iran's climate is 35.5% very arid, 29.3% arid, 20.2% semi-arid, 5% Mediterranean and 10% humid⁴¹. Therefore, about 85% of Iran's lands face significant water shortages and frequent droughts and are highly dependent on groundwater resources. In most regions, the annual precipitation is less than 100 mm⁴². In the last three decades, on average, the precipitation in humid, semi-arid and arid regions decreased by -59, -90 and -33 mm, respectively, and Tmax increased by 0.7, 1.2 and 0.2 ° C, respectively³⁶. Generally, frequent climate changes and droughts have potentially exacerbated Iran's water problems by limiting the supply of renewable water and changing the spatial and temporal characteristics of temperature and rainfall⁴³⁻⁴⁵. In addition, severe droughts in the late 1990s and 2008 affected most countries^{46,47}. Finally, all the above issues affected crop diversity in Iran.

As shown, there is a significant relationship among biodiversity indices which are affected by the number and abundance of crop species. The relationship between indices was such that Shannon index's value increased by increasing Simpson index and species richness. Specifically, species richness was associated with the evenness of species. Increasing the number of species cannot alone improve crop diversity in a region because this increase may be associated with one or more species' dominance. Only when the area of species was equal, crop diversity was increased in the region. Although many species are cultivated in Iran, it does not significantly affect the calculated diversity indices due to their low area under cultivation. Koocheki et al.⁴⁸ reported a positive and significant correlation was between Shannon diversity and species evenness index. Their results also showed that the maximum and minimum values of Shannon index for the provinces of Iran were 1.17 and 0.36, which is consistent with the present study results.

Although the Shannon and Simpson indices have experienced slight fluctuations in the last three decades, they were generally the almost constant trend. Besides, species richness was also increasing in the same period. The increase in species richness is related to the rise in the area of some species in recent.

These indices have been fluctuating for some years for various reasons. Climate change (drought and temperature fluctuations) and macro-agricultural policies (crop self-sufficiency, input subsidies, imports and exports, exchange rates, food security, and sanctions) were effective on Iran's crop diversity through influencing the area under cultivation of crops.

Investigation of the area of dominant crops in the country showed that the area of wheat and barley had a significant impact on diversity indices. Shannon diversity reduced by increasing the area under cultivation of wheat and barley and had an opposite trend to their area due to the dominance of wheat and barley and the reduced ratio of other species in the country's cultivated area. Dominance is inversely related to diversity and causes instability and vulnerability of ecosystems. Hence, by increasing the area of wheat and barley and the prevalence of monoculture in each region, the probability of damages increased due to external factors such as sudden weather changes or the spread of diseases. Kiani et al.⁴⁹ reported that cereals with 45% of cultivated area during 1981-2013 were the dominant crops in Iranian agricultural production. The area of wheat was increased by 80% in the last 50 years and its production by 347%. In recent decades, following the emphasis of officials on the self-sufficiency of strategic crops, the tendency to cultivate wheat has increased in Iran. Increasing government support policies to the agricultural sector, including guaranteed purchase, subsidies for pesticides and fertilizers, increased the area of wheat in the country, which led to the neglecting of some crops in Iran⁵⁰. Crop diversity in India was also reduced sharply over a 60-year period in certain regions, especially rice and wheat production regions under the influence of the green revolution⁵¹. Government policies in the same period, including import subsidies, price controls, and investment in the grain distribution network, may have helped increase the competitiveness of wheat and rice prices over other crops^{52,53}. Karbasi and Filsafizadeh⁵⁴ investigated the factors affecting crop diversity in Iran and reported a positive relationship between price and incentive policies (loans) with the diversity of crops. Koocheki et al.³⁴ on the diversity of Iranian cropping systems, reported that cropping systems are mainly based on wheat and rice that wheat in most parts of Iran and rice is only on the marginal of the Caspian Sea. They also pointed out that the highest area of cultivation in Iran is related to winter cereals. The reason for the development of these crops' cultivation is an adaptation to environmental stresses and low production costs.

On the other side, the impressive pressure on surface and groundwater resources, as well as recent droughts, have led to the drying up of rivers, lakes, wetlands, aqueducts and springs, declining groundwater levels, draining of wells, soil erosion, desertification and frequent dust storms, loss of biodiversity and increasing pressure on rural livelihoods^{55,56}, and finally a decline in food security in the future of Iran.

Conclusions

Analyzing the statistical data allowed us to have a spatial and temporal estimate of crop diversity in different regions of Iran. The crop diversity in Iran at the national level was almost constant during 1991-2018, but different trends were observed at the sub-national level. These different trends in each region are influenced by various internal and external factors that affect the selection and cultivation of crops. The cultivation of wheat and barley in parts of Iran has reduced crop diversity in these regions, and on the other hand, these products are very important for the country in terms of food security. In general, Iran's agricultural system is based on wheat cultivation and is the main crop in most crop rotations. Additionally, a significant difference was between crop diversity of rainfed and irrigated cultivation, which is affected by climatic conditions prevailing in Iran. Arid and semi-arid climates determine the cultivation of rainfed crops, and farmers face limited crop cultivation and are forced to cultivate a limited number of crops. Finally, the study results show low diversity of crops and an almost constant trend of crop diversity in agroecosystems in Iran, the important consequences of which will be instability and production risk in the future.

Methods

Study area. Iran is located in the southwest of Asia that bounded by latitudes 25° N to 45° N and longitudes 44° E to 63.5° E (Fig. 1). Two important mountain ranges of the country, including the Zagros in the west and the Alborz in the north, are the cause of non-uniformity of precipitation and humidity, which have led to different climatic conditions in this country. For this investigation, 67 sites with different climate types were selected based on the highest area under crop cultivation (At least two sites in each province). During the study period (1983 to 2018), 32.8%, 34.4% and 32.8% of these sites had an average cultivated area of less than 50, more than 50 and 100 thousand hectares, respectively. The geographical of the investigated sites and their climate conditions are presented in Fig. 1.

Index calculations. The most intuitive and basic measure for showing the biodiversity of a region is species richness (S), which is obtained by counting the number of different species in a habitat or region. Species richness is not sensitive to the abundance and relative abundance distribution of species⁵⁷.

The Shannon-Wiener index (H') is known as the measure of uncertainty based on information's entropy. The uncertainty of the forecasts for a society that is dominated by one species (low diversity) is low; because, in sampling, the randomly selected species is likely to be the dominant species. Besides, when species diversity is high in society, uncertainty is high^{58,59}. H' was calculated as follows^{60,61}:

$$H' = - \sum_{i=0}^n P_i \ln P_i \quad (1)$$

where P_i (ni/N) is the proportion of the total crop area (N) that belongs to crop i(ni). The log was given in base 2⁶².

Another criterion that is broadly used in biodiversity measurement is the Simpson diversity index (1-D). This index indicates the probability that two randomly collected individuals from a community belong to different species^{58,63,64}. The Simpson diversity index can be defined as follows:

$$1 - D = 1 - \sum_{i=0}^n P_i^2 \quad (2)$$

This equation is also used when using parameters such as canopy, biomass, production and area of crop. The value of the Simpson diversity index varies from zero to one. Higher values of the index (1) indicate higher diversity and vice versa^{58,64}. In general, Simpson's reciprocal index was used to determine the value of evenness. The values close to zero and one represent lower and higher evenness, respectively⁶⁵.

Spatial and Statistical Analyses. Three biodiversity indices, including Shannon diversity index (H'), Simpson diversity index (1-D) and Species richness index (S) were calculated for rainfed, irrigated cultivation and the total area of both in Iran between 1991 and 2018. For calculating H' and E, species abundance values were considered equal to crop area. The 'vegan' package in R software version 4.0.3 using for calculating biodiversity indices⁶⁶.

The interpolation of diversity indices was performed based on the inverse distance weighting (IDW) method using Arcmap 10.8 software. The interpolation accuracy of IDW algorithm was determined by the root-mean-square error (RMSE).

Besides, the trend of H', E and SR during the last three decades and the relationship among these indices were investigated using polynomial and linear regression. Also, for detecting a significant trend in H', E and SR, Non-parametric Mann-Kendall test were applied. Mann-Kendall (MK) test^{67,68} statistically evaluates if there is an upward or downward trend of the variable over time. A monotonic upward (downward) trend means that the variable consistently increases (upward) through time, but the trend may or may not be linear. For more detailed information about the MK test, refer to Bannayan et al.⁶⁸. All data analysis was done with R by ggplot2 and Kendall R-packages.

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Author Contributions

S.A., L.J. and A.A. conceived the study. L.J. supervised the study. S.A. Analyzed the data and prepared all figures. S.A., A.A. and L.J. wrote the manuscript. All authors have read and approved the final manuscript.

Competing interests

The authors declare no conflict of interest.

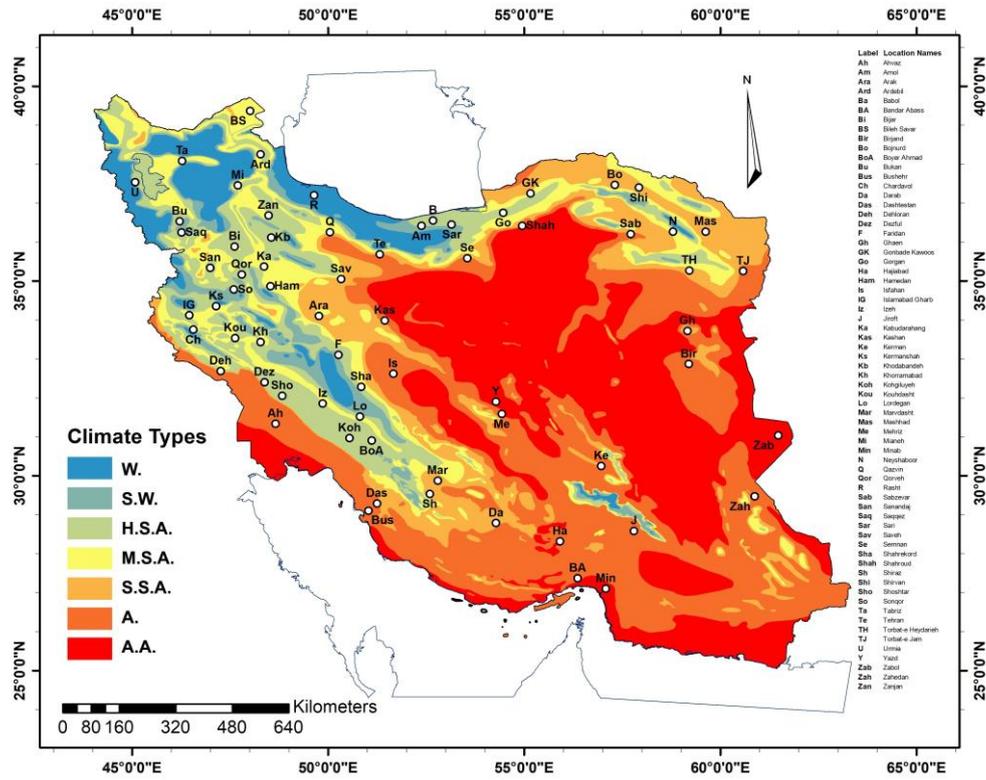
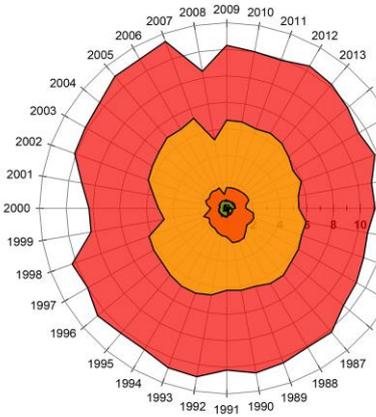
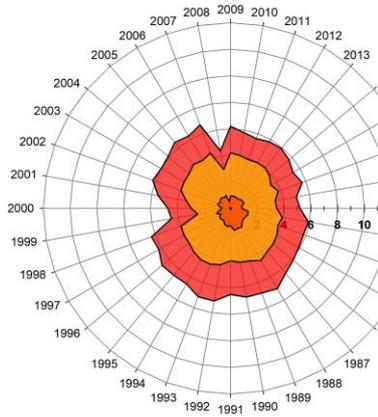


Figure 1. The geographical of the investigated sites (white circle) based on the highest area under crop cultivation in Iran.

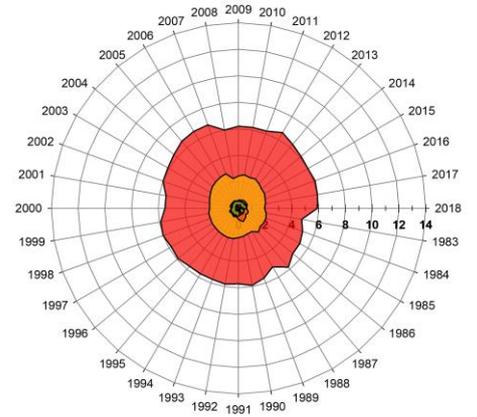
a. Total under cultivation (m ha)



b. Area under rainfed cultivation (m ha)



c. Area under irrigated cultivation (m ha)



Major Crops
Wheat Rice Barley Maize Alfalfa Cotton Sugar beet Total Crops

Figure 2. Area of 7 major crops and other crops and vegetables under irrigated (c) cultivation, rainfed (b) and both of them (a) in Iran between 1983 and 2018.

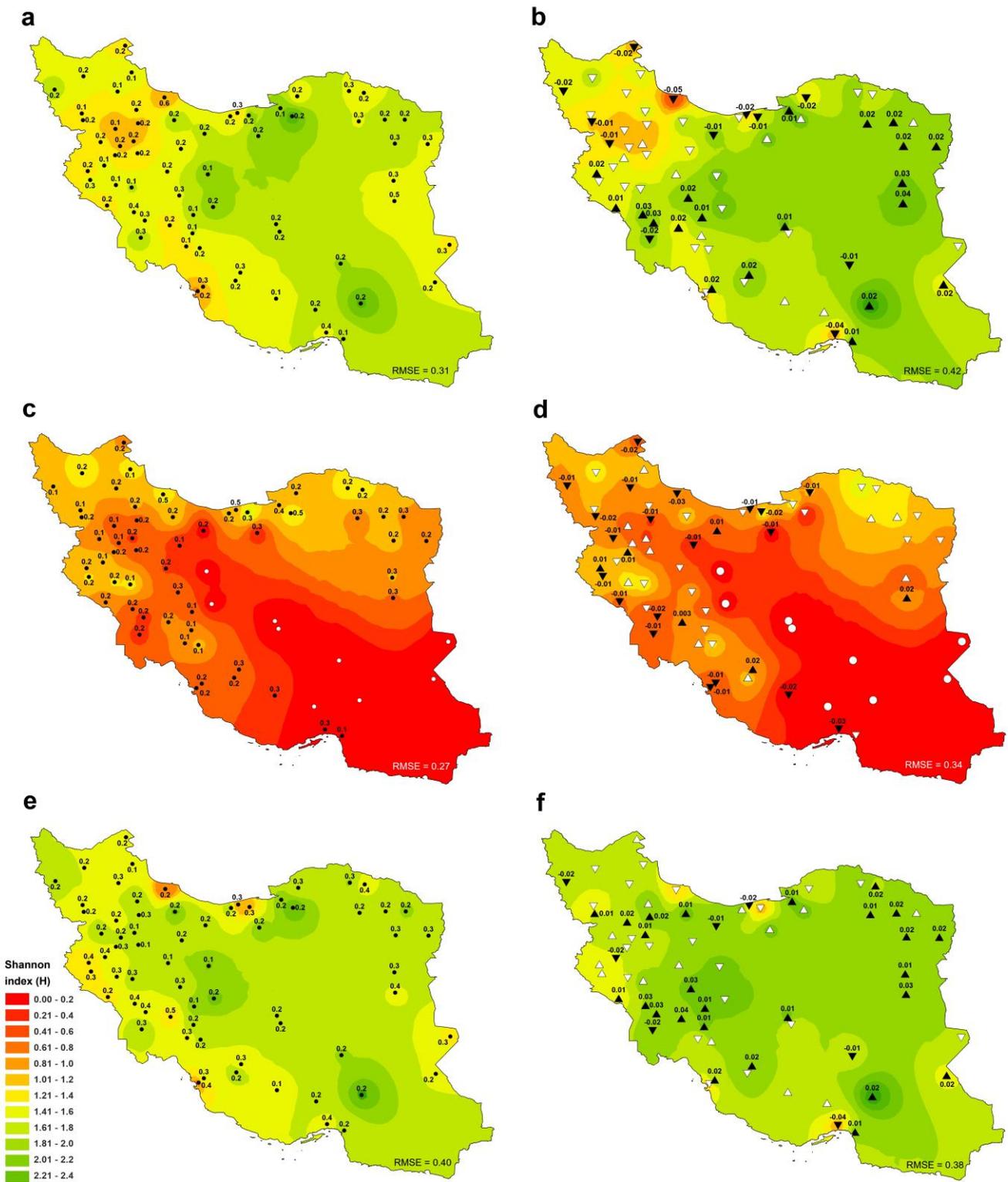


Figure 3. Spatial distribution of Shannon diversity index (H') trends and tendencies in rainfed cultivation (c, d), irrigated cultivation (e, f) and both of them (a, b) in Iran between 1991 and 2018. Significant positive and negative trends are shown by (\blacktriangle) and (\blacktriangledown) and insignificant upward and downward trends are depicted by (\triangle) and (\triangledown), respectively. White circle (\circ) also indicates the lack of rainfed cultivation in the site. Besides, the numbers next to the triangle and circle indicate the average rate of change (slope) (b, d and f) and standard deviation (STDV) (a, c and e) in the variable, respectively. Also, the root-mean-square error (RMSE) of the interpolated values based on the inverse distance weighting method (IDW) was specified at the bottom of each figure.

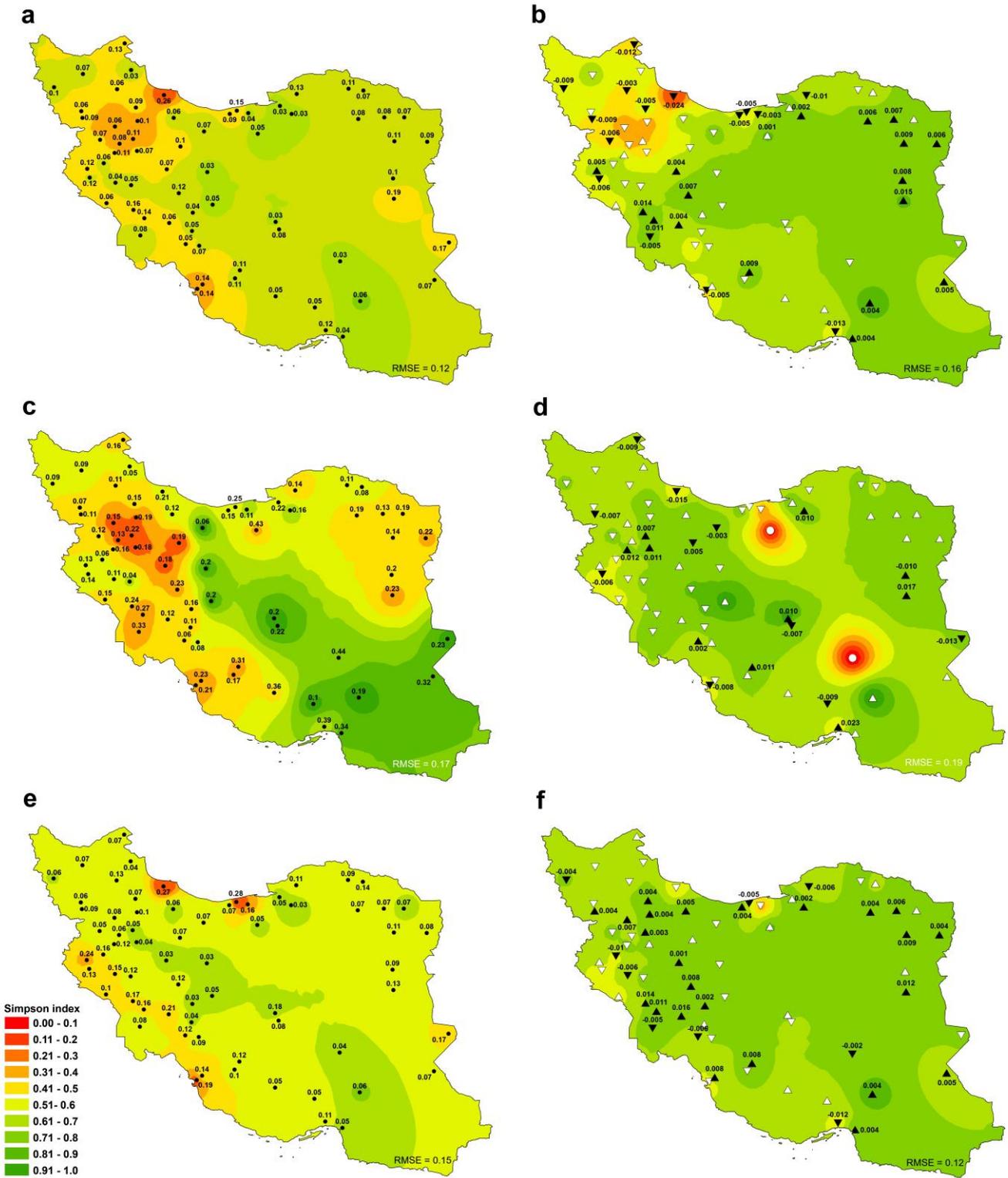


Figure 4. Spatial distribution of Simpson diversity index trends and tendencies in rainfed cultivation (c, d), irrigated cultivation (e, f) and both of them (a, b) in Iran between 1991 and 2018. Significant positive and negative trends are shown by (\blacktriangle) and (\blacktriangledown) and insignificant upward and downward trends are depicted by (\triangle) and (\triangledown), respectively. White circle (O) also indicates the lack of rainfed cultivation in the site. Besides, the numbers next to the triangle and circle indicate the average rate of change (slope) (b, d and f) and standard deviation (STDV) (a, c and e) in the variable, respectively. Also, the root-mean-square error (RMSE) of the interpolated values based on the inverse distance weighting method (IDW) was specified at the bottom of each figure.

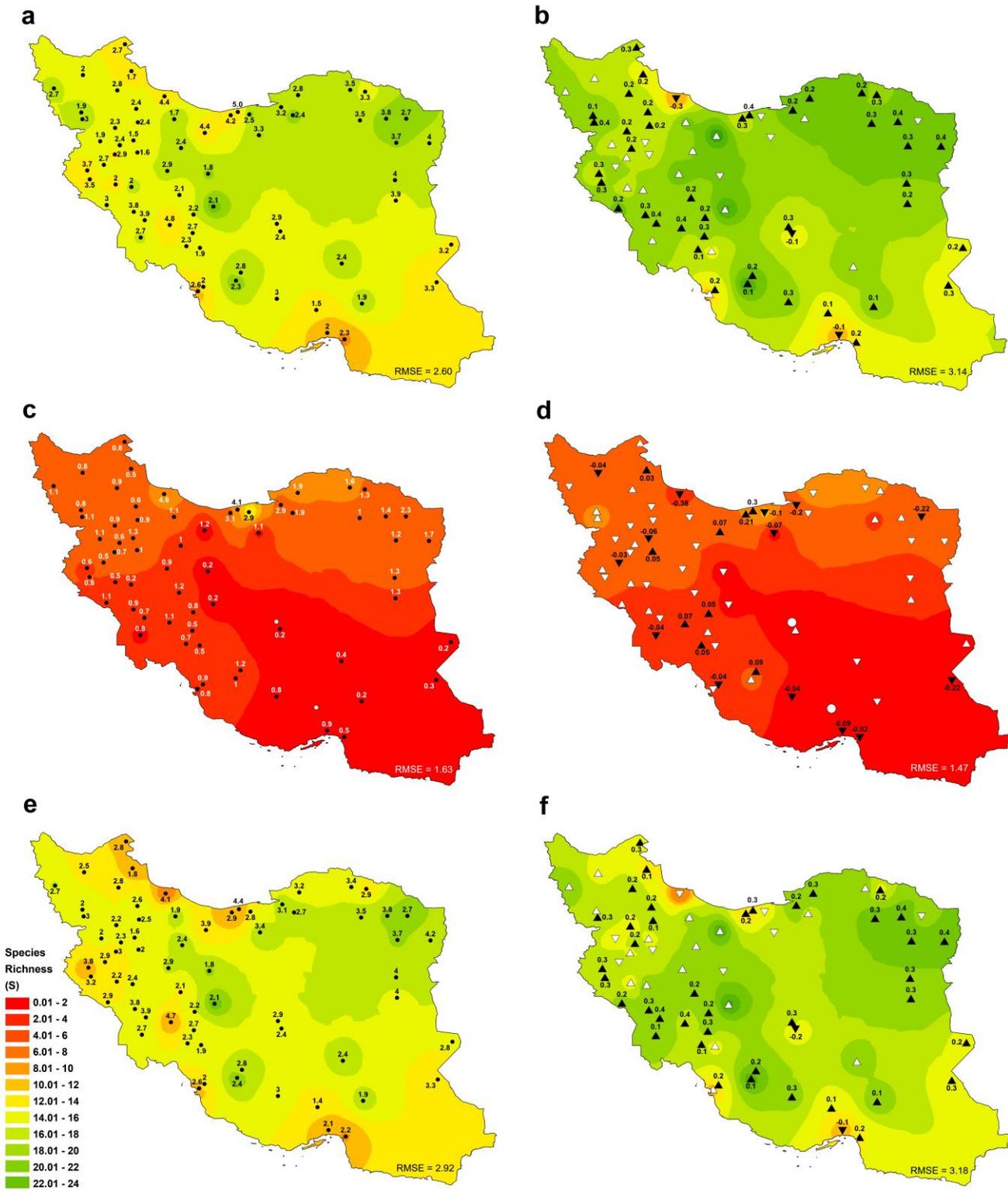


Figure 5. Spatial distribution of Species richness index (S) trends and tendencies in rainfed cultivation (c, d), irrigated cultivation (e, f) and both of them (a, b) in Iran between 1991 and 2018. Significant positive and negative trends are shown by (▲) and (▼) and insignificant upward and downward trends are depicted by (△) and (▽), respectively. White circle (○) also indicates the lack of rainfed cultivation in the site. Besides, the numbers next to the triangle and circle indicate the average rate of change (slope) (b, d and f) and standard deviation (STDV) (a, c and e) in the variable, respectively. Also, the root-mean-square error (RMSE) of the interpolated values based on the inverse distance weighting method (IDW) was specified at the bottom of each figure.

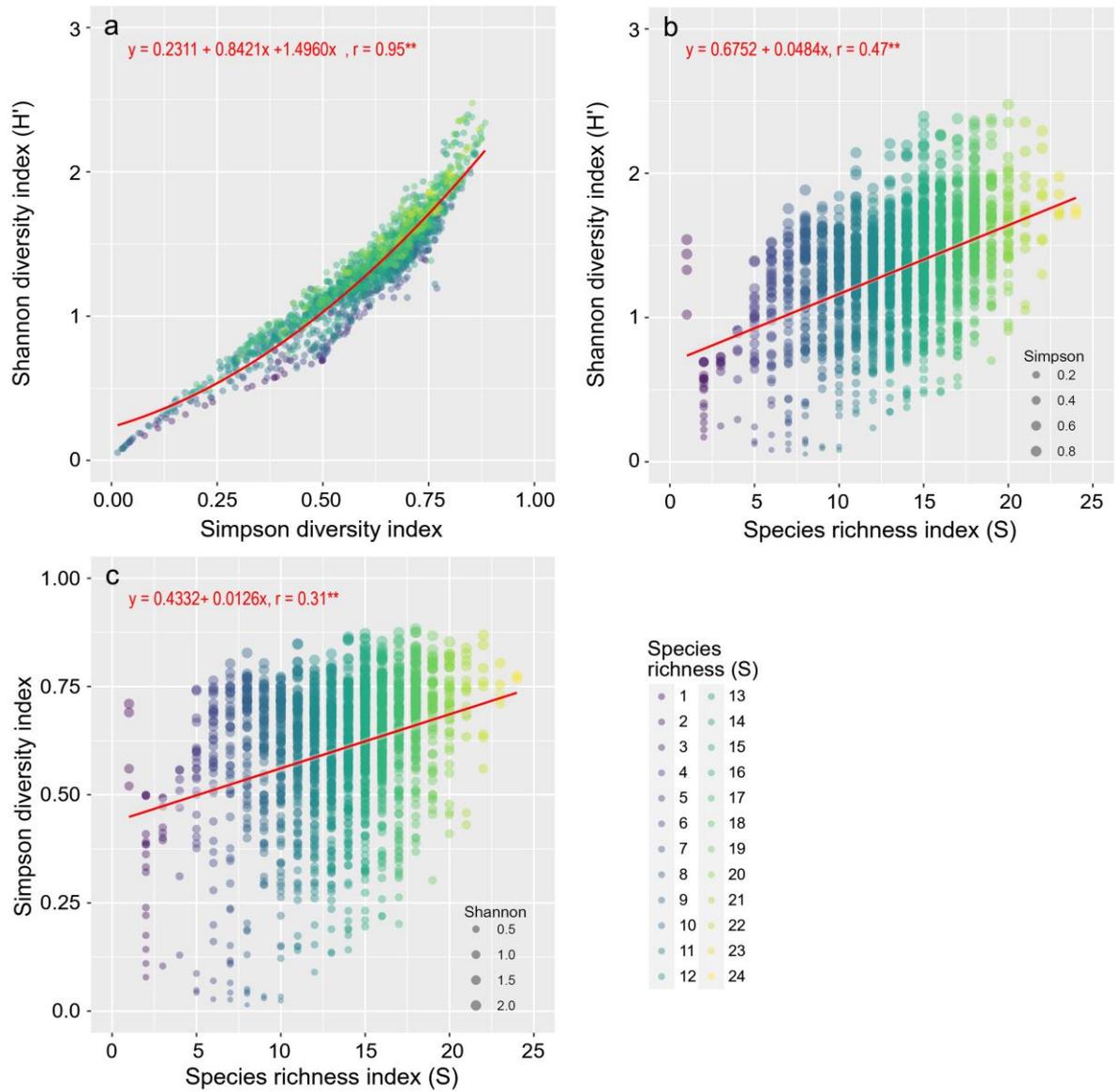


Figure 6. The relationship among Shannon diversity index (H') (a), Simpson diversity index (b) and Species richness index (S) (c) in Iran between 1991 and 2018. The solid line is the polynomial (a) and linear (b and c) regression fit to the points (n=1748). Significant trends ($p \leq 0.01$) shown by **.

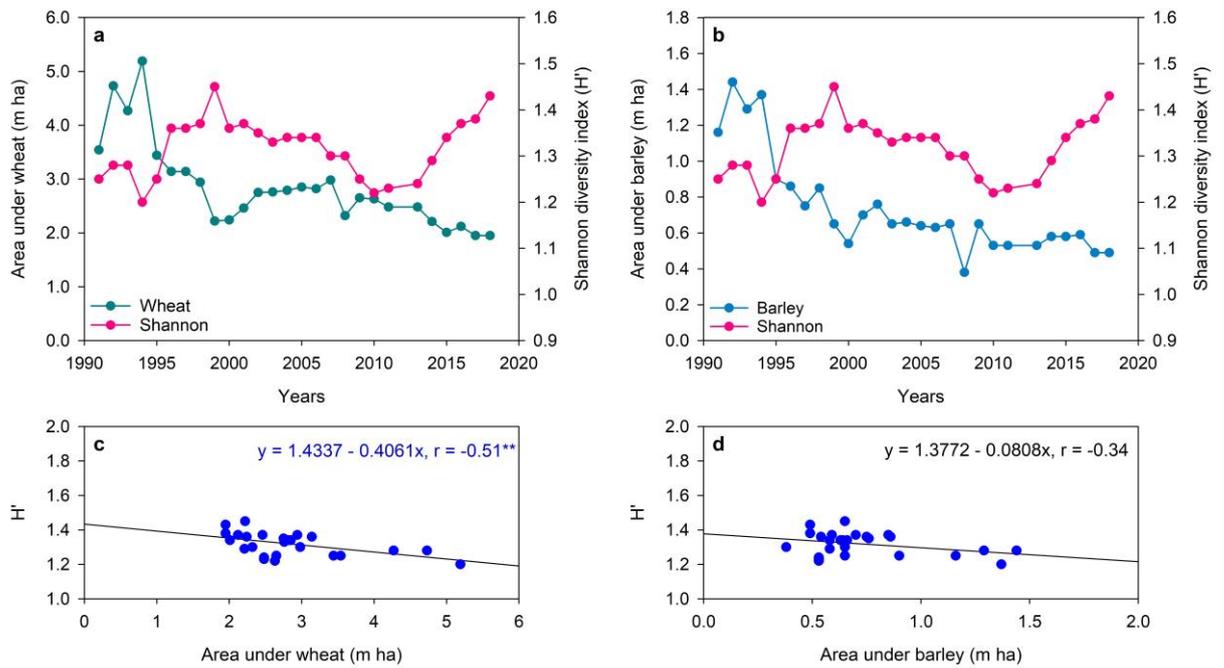


Figure 7. The trend of Shannon diversity index (H') (a and b) and area under wheat (a) and barley (b) cultivation in Iran between 1991 and 2018. The relationship between Shannon diversity index (H') and area under wheat (c) and barley (d) cultivation in Iran between 1991 and 2018. The solid line is the linear regression fit to the blue points (n=28). Significant trends ($p \leq 0.01$) shown by **.

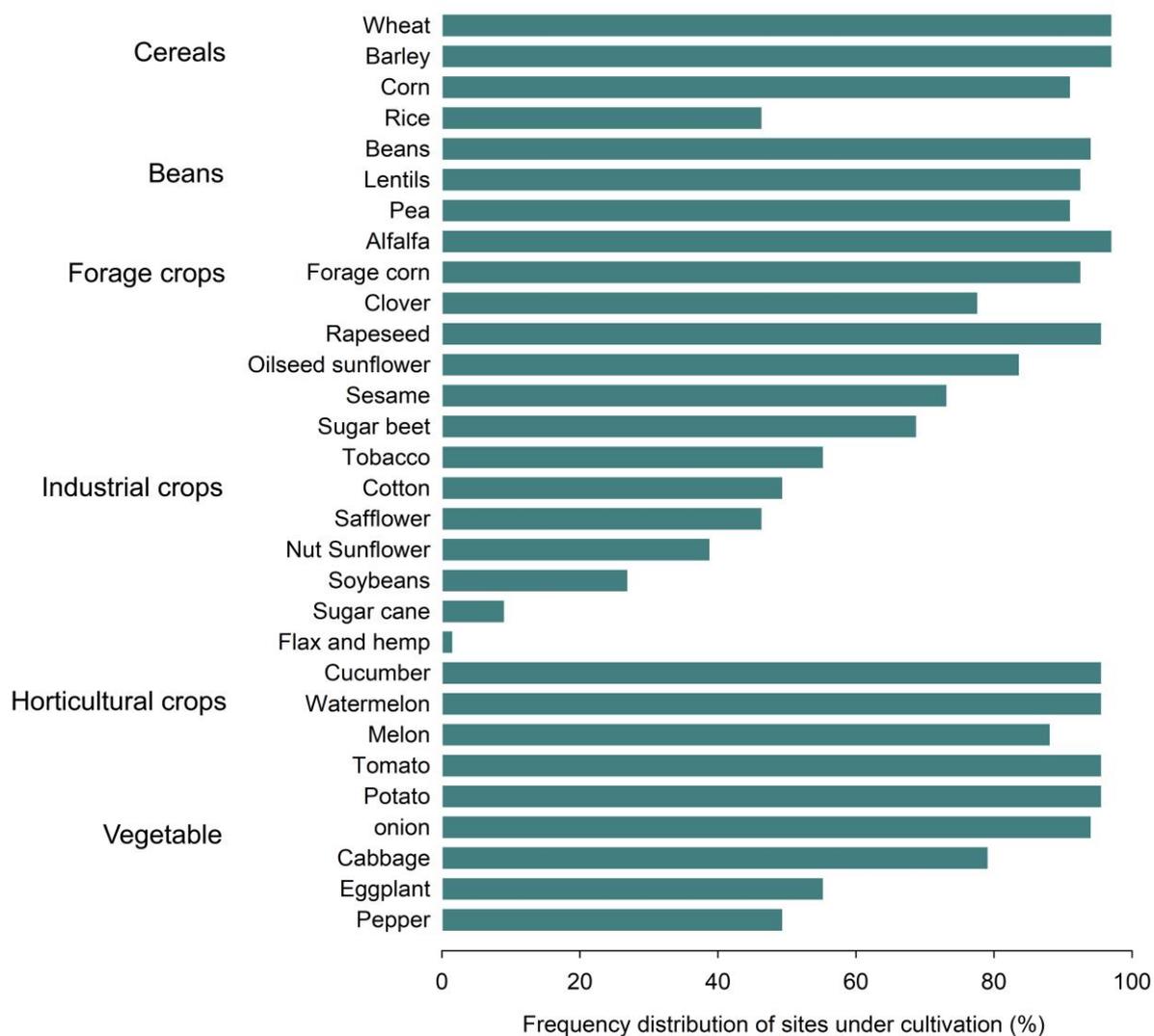


Figure 8. List of crops and the frequency distribution of sites under their cultivation in Iran

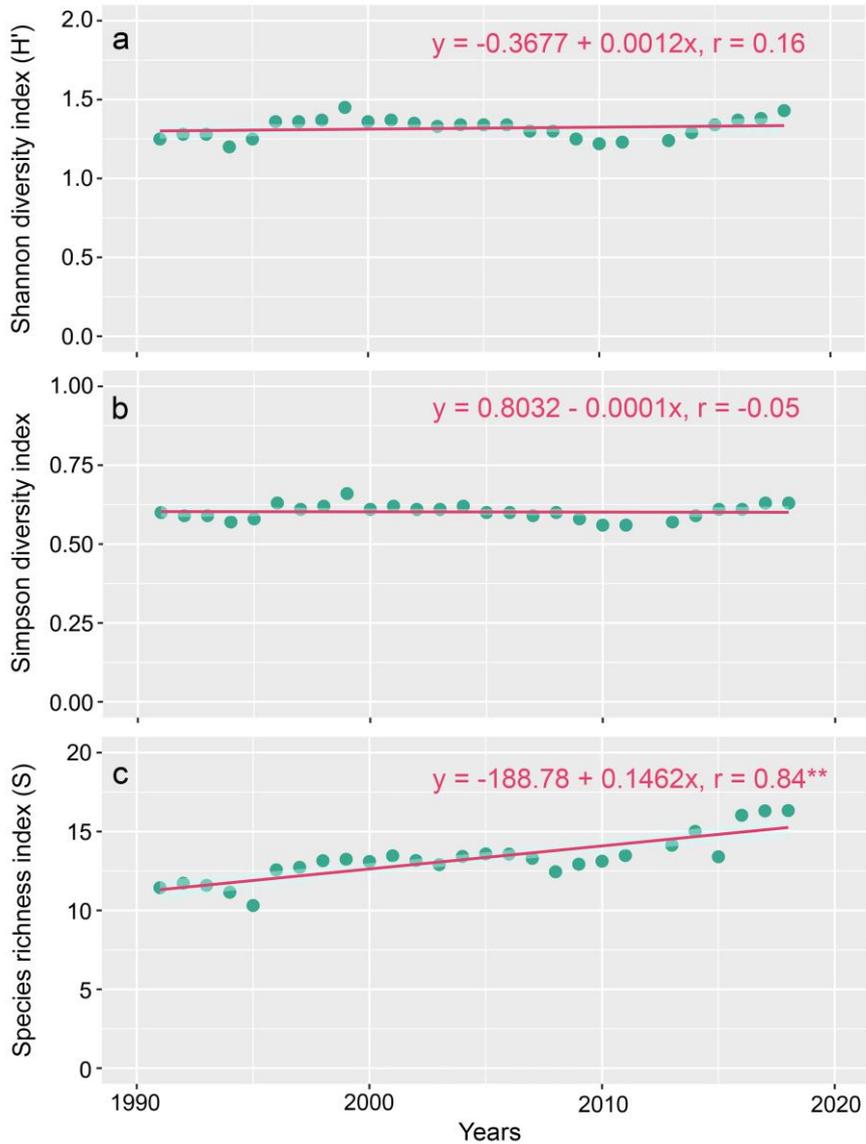


Figure 9. The trend of Shannon diversity index (H') (a), Simpson diversity index (b) and Species richness index (S) (c) in Iran between 1991 and 2018. The solid line is the linear regression fit to the green points (n=27) and 95% confidence interval shown by light-green shading. Significant trends ($p \leq 0.01$) shown by **.

Figures

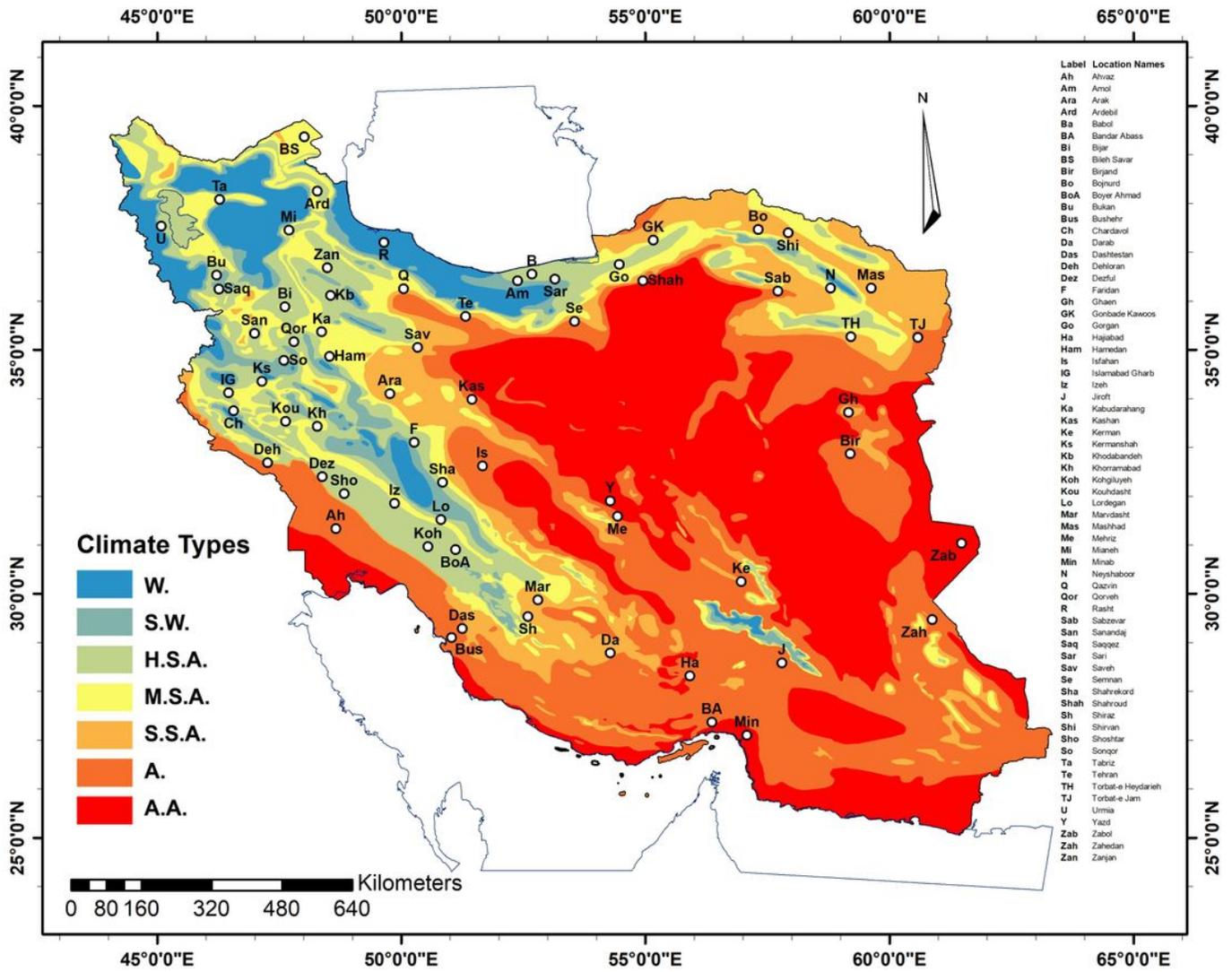
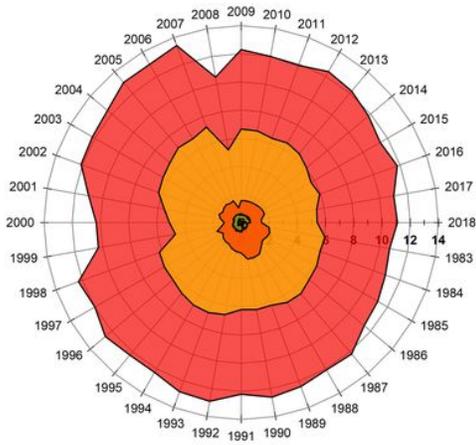


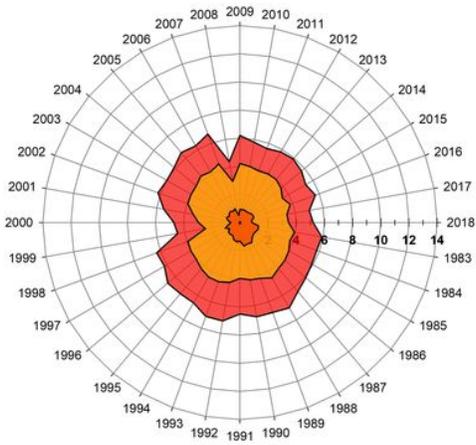
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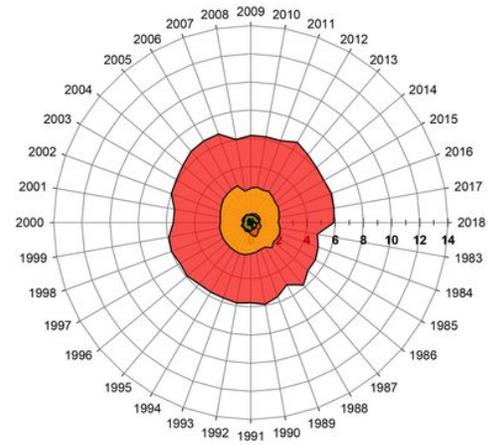


Figure 2

Area of 7 major crops and other crops and vegetables under irrigated (c) cultivation, rainfed (b) and both of them (a) in Iran between 1983 and 2018.

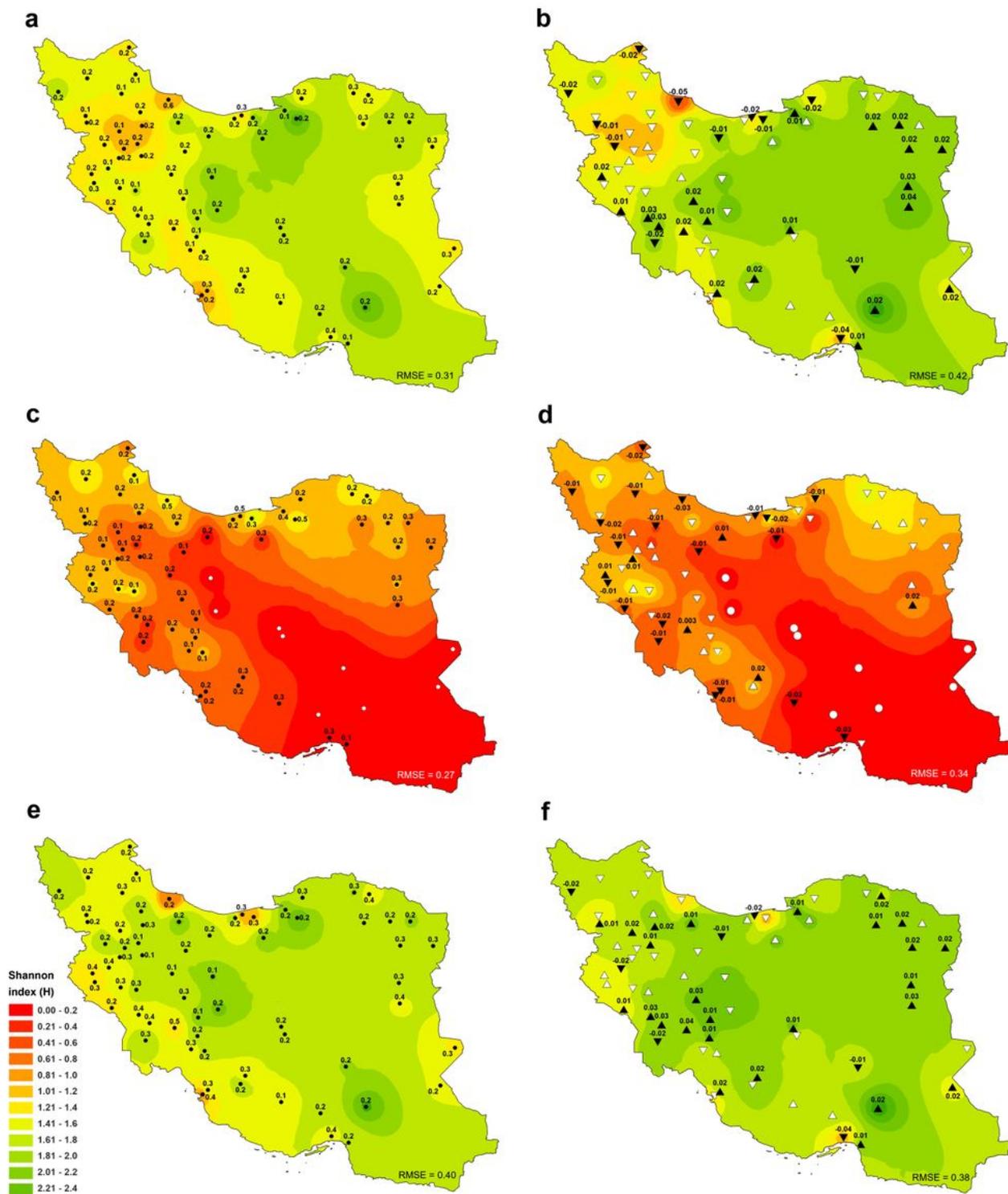


Figure 3

Spatial distribution of Shannon diversity index (H') trends and tendencies in rainfed cultivation (c, d), irrigated cultivation (e, f) and both of them (a, b) in Iran between 1991 and 2018. Significant positive and negative trends are shown by (▲) and (▼) and insignificant upward and downward trends are depicted by (○) and (◻), respectively. White circle (○) also indicates the lack of rainfed cultivation in the site. Besides, the numbers next to the triangle and circle indicate the average rate of change (slope) (b, d and f) and

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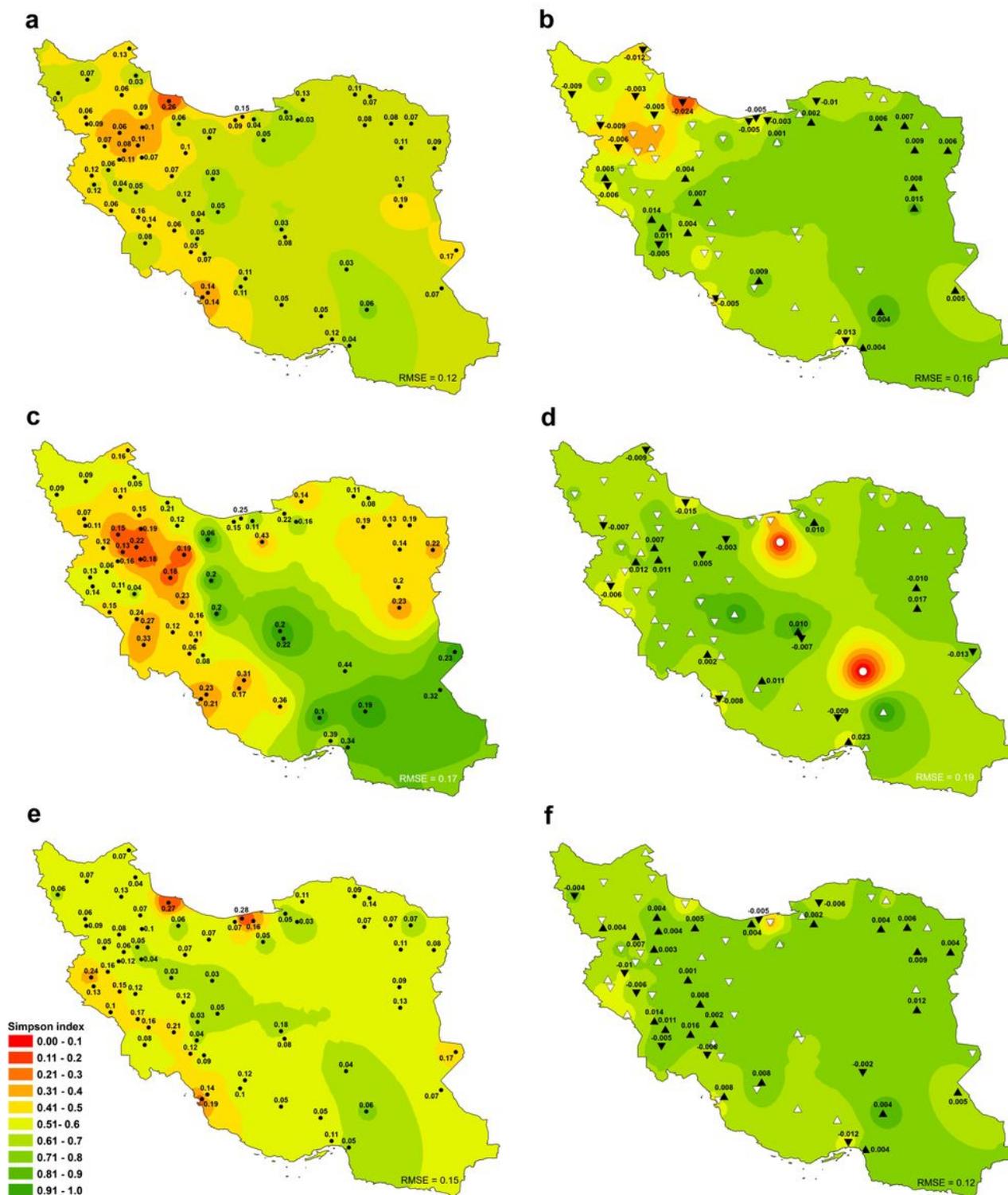


Figure 4

Spatial distribution of Simpson diversity index trends and tendencies in rainfed cultivation (c, d), irrigated cultivation (e, f) and both of them (a, b) in Iran between 1991 and 2018. Significant positive and negative

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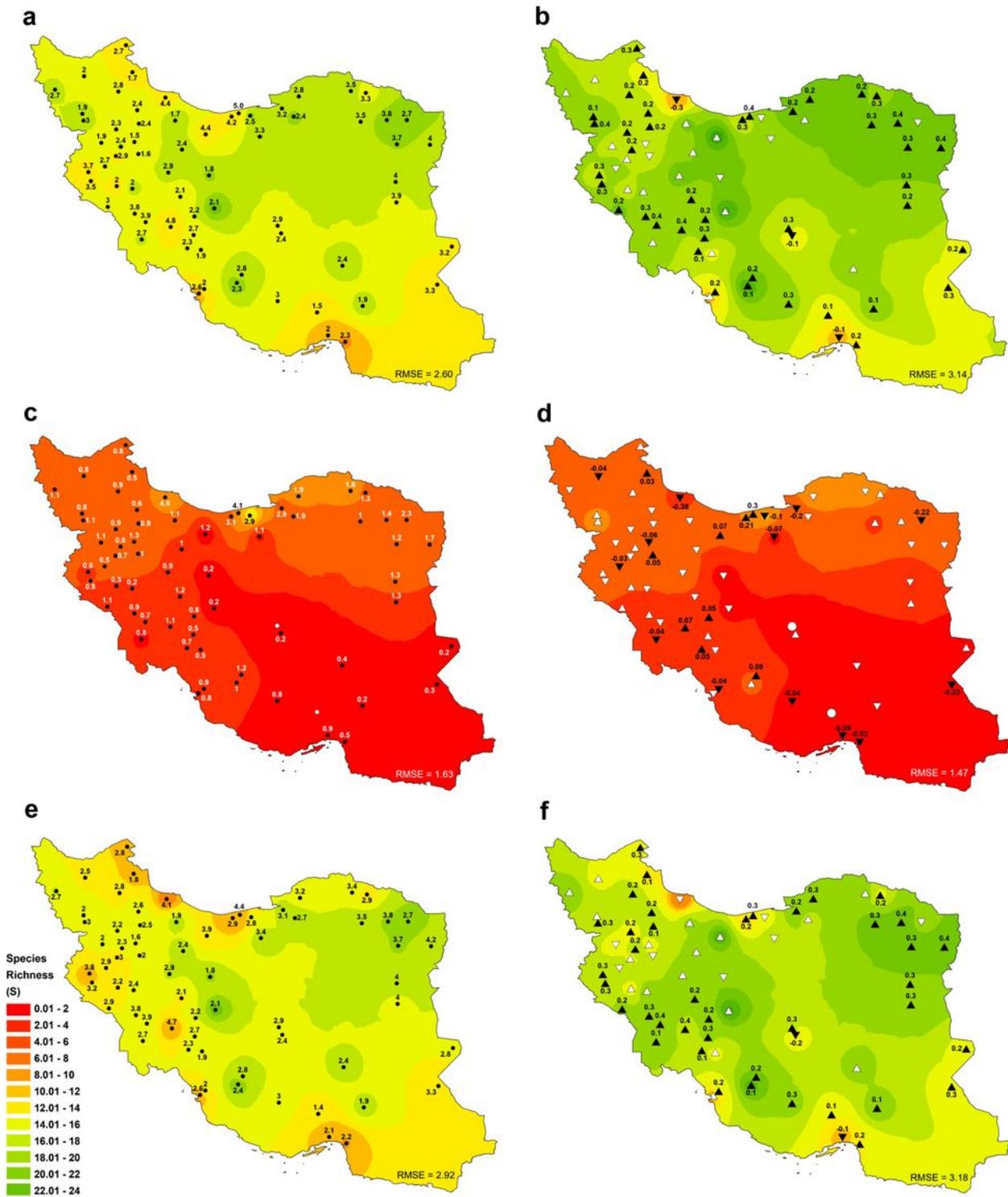


Figure 5

Spatial distribution of Species richness index (S) trends and tendencies in rainfed cultivation (c, d), irrigated cultivation (e, f) and both of them (a, b) in Iran between 1991 and 2018. Significant positive and negative trends are shown by (☒) and (☒) and insignificant upward and downward trends are depicted by (☒) and (☒), respectively. White circle (☒) also indicates the lack of rainfed cultivation in the site. Besides, the numbers next to the triangle and circle indicate the average rate of change (slope) (b, d and f) and standard deviation (STDV) (a, c and e) in the variable, respectively. Also, the root-mean-square error (RMSE) of the interpolated values based on the inverse distance weighting method (IDW) was specified at the bottom of each figure.

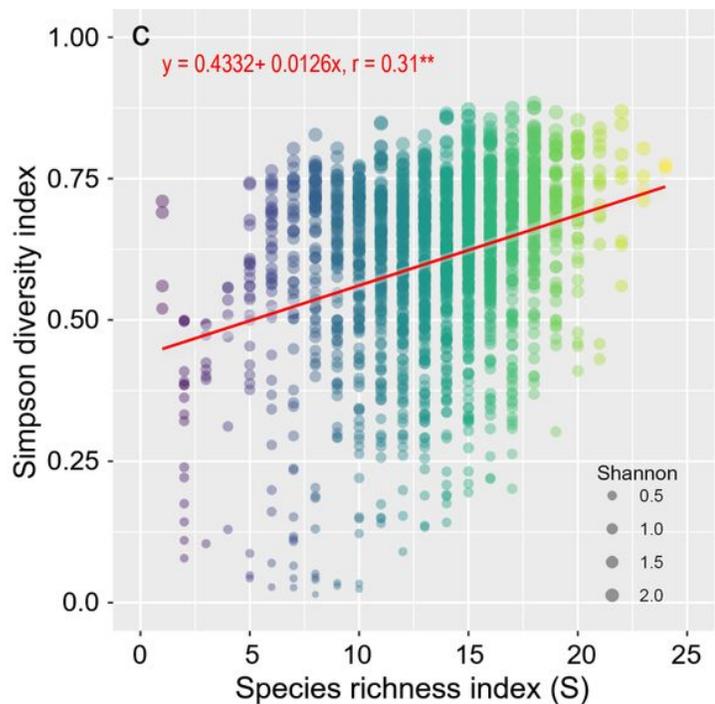
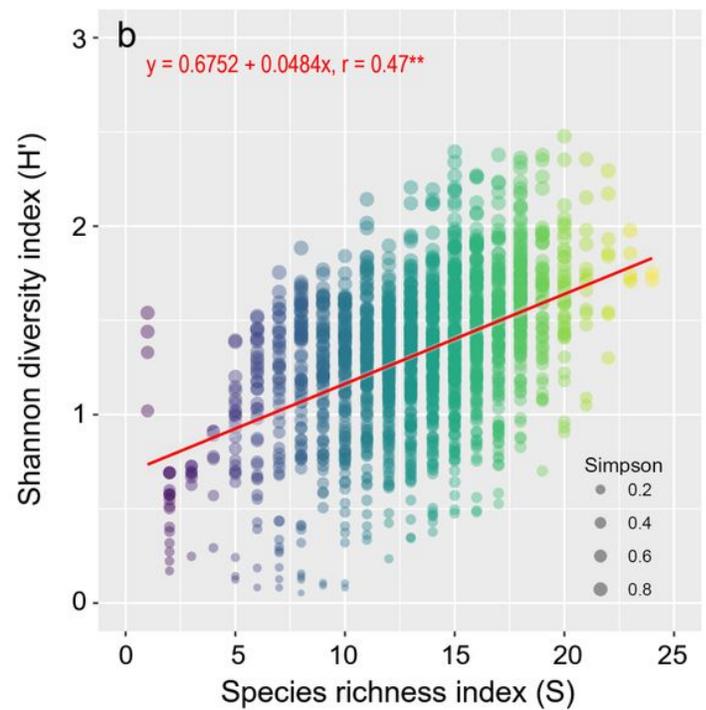
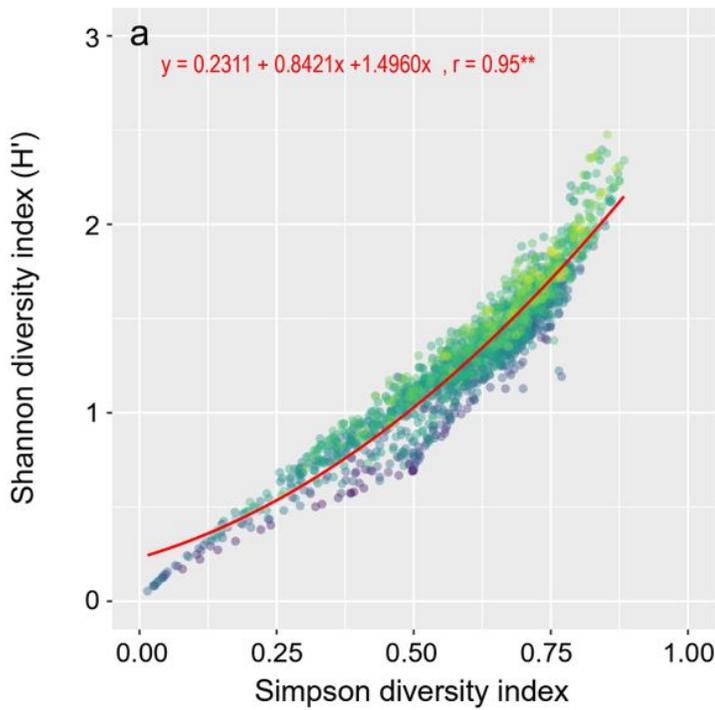


Figure 6

The relationship among Shannon diversity index (H') (a), Simpson diversity index (b) and Species richness index (S) (c) in Iran between 1991 and 2018. The solid line is the polynomial (a) and linear (b and c) regression fit to the points ($n=1748$). Significant trends ($p \leq 0.01$) shown by ******.

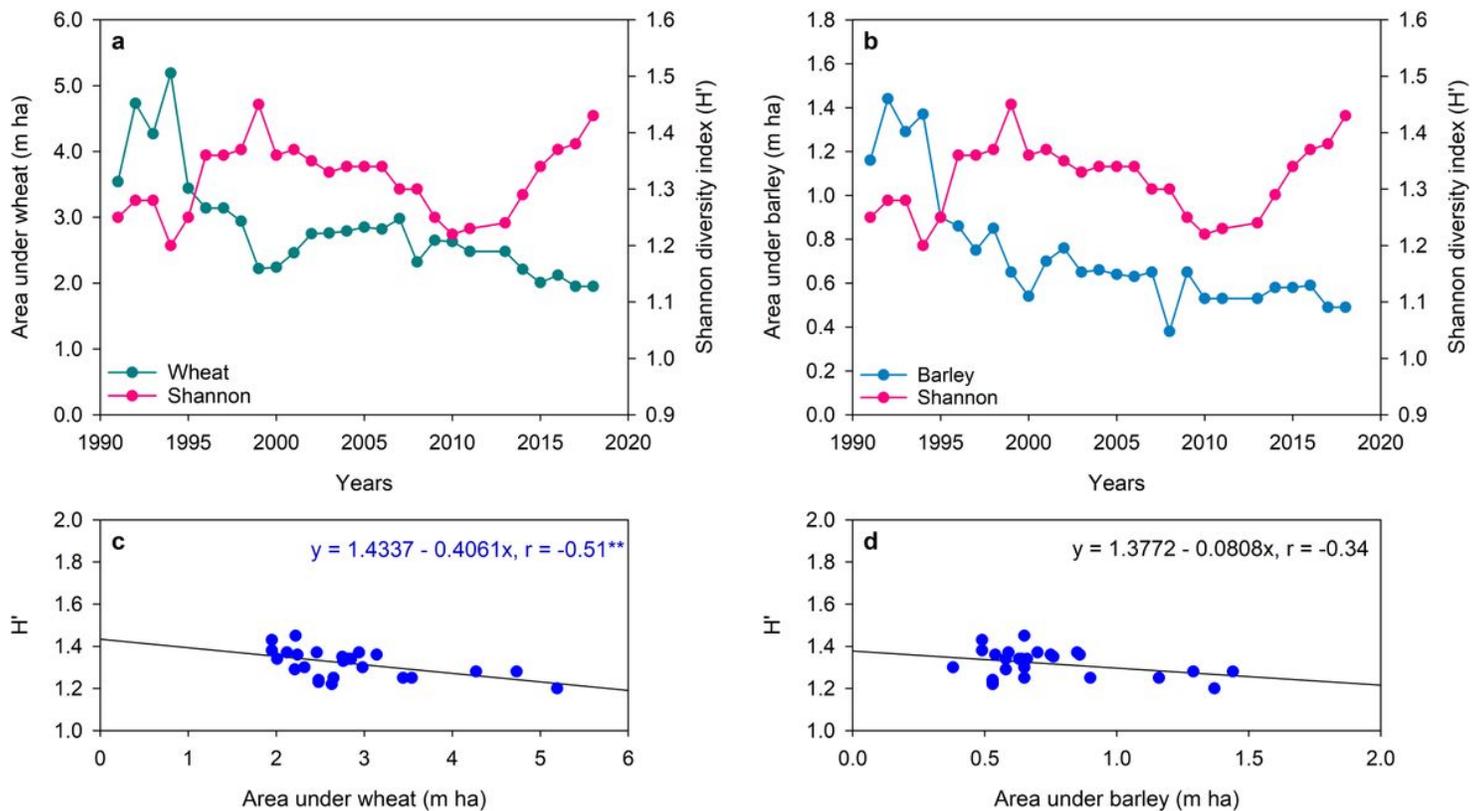


Figure 7

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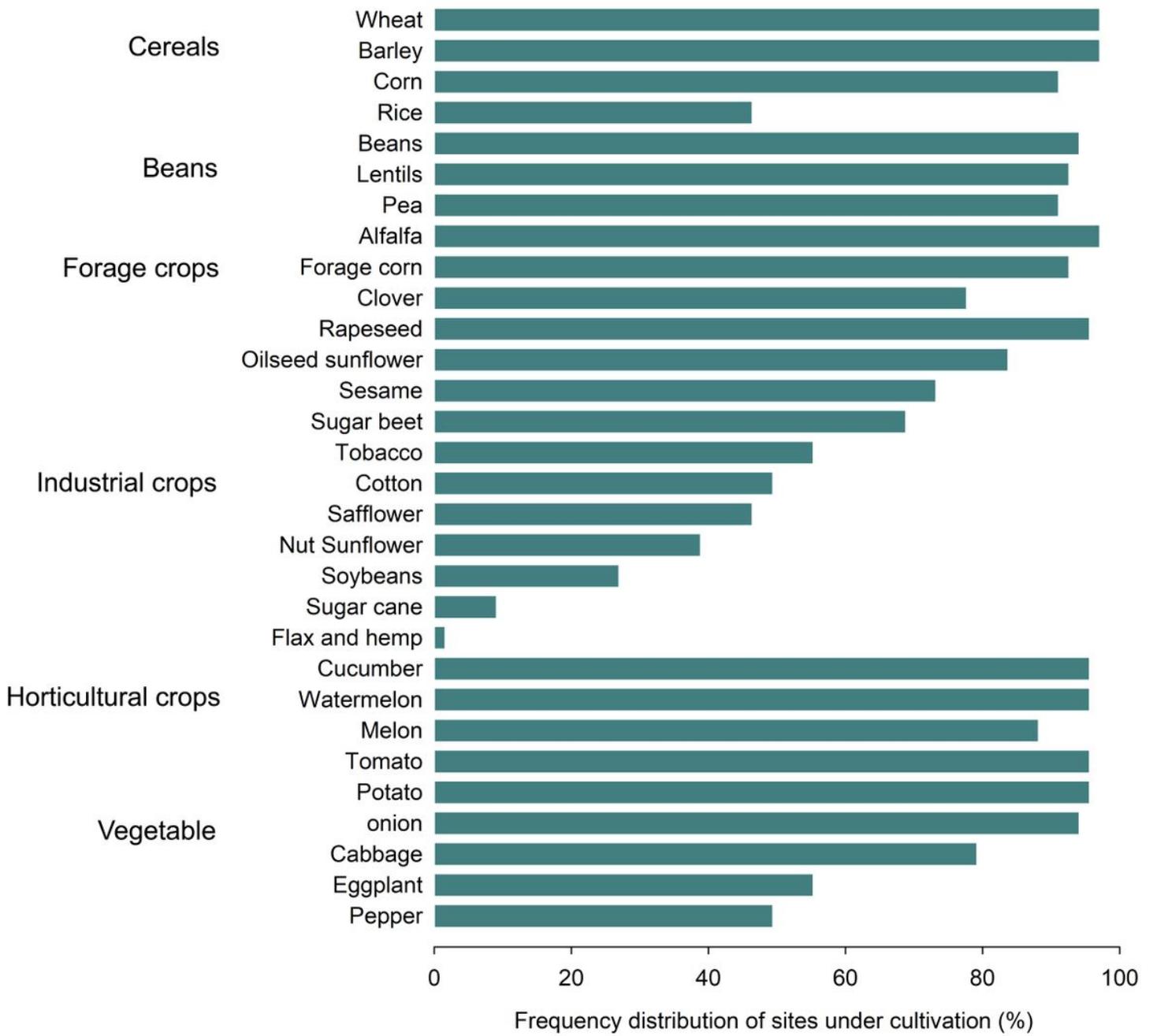


Figure 8

List of crops and the frequency distribution of sites under their cultivation in Iran

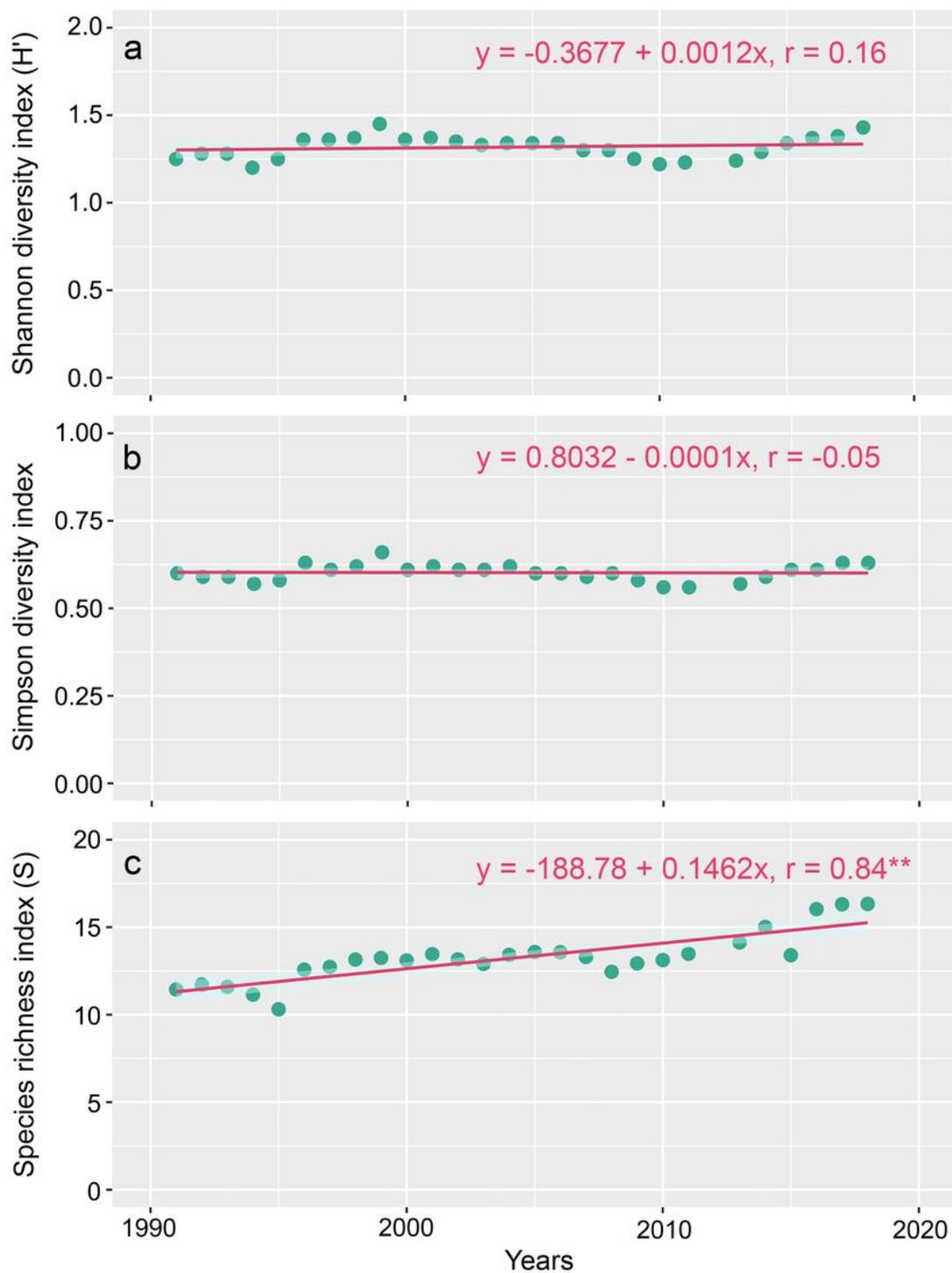


Figure 9

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