

The pollen ratio of indicator taxa in steppe and forest-steppe landscapes of Altai Krai

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Abstract

The pollen ratios of key plant taxa in the spectra of palynological samples are widely used to indicate changes in vegetation, landscapes and climate. In this study, based on the analysis of pollen spectra obtained from Tauber traps and topsoil samples, the main ratios of indicator taxa (*Artemisia*/Chenopodiaceae (A/C) and (*Artemisia* + Chenopodiaceae)/Poaceae (A + C)/P) were calculated for the steppe and forest-steppe landscapes of Altai Krai. The results show that the (A+C)/P ratio calculated for pollen traps makes it potentially possible to distinguish steppe and forest-steppe landscapes. The (A+C)/P ratio has a positive correlation with the mean annual precipitation for samples collected in Tauber traps. A variety of factors significantly influence the values of the pollen ratio, including the proportion of indicator taxa in the community, their pollen productivity and volatility, as well as the structure of natural and anthropogenically transformed vegetation. In other words, the study of the zonality of the ratios of indicator taxa in pollen spectra requires a certain data set (a set of points and samples), as well as an analysis of the deviating maximum and minimum values of these ratios and the construction of a physical model of their formation taking into account all probable factors.

Keywords

Altai Krai, steppe, forest-steppe, indicator taxa, pollen ratio

Introduction

In the study of past climate change and associated vegetation transformation, one of the main methods is the analysis of fossil pollen spectra (Xu et al. 2016). The central problem of such studies is the interpretation of the percentage of certain taxa pollen in the selected spectrum. In most cases, the interpretation of pollen spectra is based on the analysis of the presence and abundance of selected indicator taxa (Gaceur et al. 2017, Lee et al. 2024) and is presented as the concentration or percentage of pollen types. However, in some cases, indicator taxa are absent or, in contrast, abundantly represented, which significantly complicates the interpretation of the results obtained. Therefore, various pollen ratios have been developed, such as *Artemisia*/Cyperaceae (A/Cy) (Herzschuh 2007, Zhao & Herzschuh 2009), *Pinus*/*Artemisia* (Xu et al. 2007); Poaceae/*Artemisia* (Po/A) (Tang et al. 2009), Cyperaceae/Poaceae (Cy/Po) (Cour et al. 1999), Cyperaceae/(Poaceae + *Artemisia*) (Cy/(Po + A)) (Tang et al. 2009), *Artemisia*/*Betula* (A/B), Poaceae/(*Artemisia* + Chenopodiaceae) (Po/(A + C)) (Fowell et al. 2003), *Artemisia*/Chenopodiaceae (A/C) as semiquantitative indicators (Zhang et al. 2018).

The *Artemisia*/Chenopodiaceae (A/C) ratio is used as an indicator of temperature and aridity variability in a number of regions: arid and semi-arid areas of China (Herzschuh 2007, Huang et al. 2009), southeastern Mongolia (Liu et al. 2006), and mountains. In addition to arid and semi-arid regions (most often desert and steppe areas, respectively), this ratio has been calculated for meadows and forests (Zhao et al. 2012). However, such studies are mainly local in nature, which limits the interpretation of data on fossil pollen spectra and reconstruction for other sites. For a more detailed distinction between steppe and forest-steppe landscapes, the ratio of pollen from the sum of percentages of wormwood and goosefoot family divided by the percentage of grasses (*Artemisia* + Chenopodiaceae)/Poaceae (A + C)/P) is used, since with increasing humidity, the proportion of grass pollen in the composition of phytocenoses increases.

Several studies have been conducted on modern surface pollen spectra for the Republic of Altai and Altai Krai (Pelánková & Chytrý 2009; Blyakharchuk et al. 2023, Kuryatnikova et al. 2024). However, insufficient attention has been paid to the study of semiquantitative indicators, especially for the plain part of Altai Krai located within the steppe and forest-steppe zones. It is worth noting that the results of the palynological analysis of lake sediments in the steppe zone are available for this territory (Rudaya et al. 2012, 2020), but the ratios of indicator taxa based on modern pollen spectra have not been calculated, which determines the relevance of this work. Furthermore, this area represents a large regional ecological environment. On the one hand, this is due to its location in the contact zone between the plains of Western Siberia and the mountain structures of the Altai-Sayan Mountain Country. On the other hand, it is crossed by an imaginary line that delimits humid and arid landscapes based on the balance of heat and moisture. The long-term and large-scale impact (primarily plowing) has also significantly influenced the composition

and structure of vegetation. The results of these studies will expand our understanding of modern pollen-vegetation relationships and provide valuable information for reconstructing long-term climate change and vegetation dynamics.

The aim of the work is to test the effectiveness of the calculated pollen ratios A/C and $(A + C)/P$ within the steppe and forest-steppe zones of Altai Krai, as well as to identify the conditions and limitations of their use to study modern pollen-vegetation relationships in steppe and forest-steppe landscapes.

Materials and methods

The material for this study was based on recent samples collected using two schemes in the plain and foothill parts of Altai Krai belonging to the steppe and forest-steppe zones. The territory includes three large geomorphological regions: the Kulundinskaya Lowland Plain, the Priobskoye Upland Plato, and the Predaltaiskaya Piedmont Plain (foothills). Figure 1 shows the physiographic regionalization of the territory and the location of sampling points. The first scheme involved sampling using Tauber traps installed in accordance with the requirements of the international Pollen Monitoring Program (Hicks et al. 1996). Traps were installed from 3 May to September 20, 2022, in the steppe and forest steppe zones (Table 1). Although the installation dates did not coincide with the beginning of tree pollination, this did not affect the accumulation of pollen for *Artemisia*, *Chenopodiaceae*, and *Poaceae*, which bloom primarily in the second half of the growing season. According to the pollen calendar for adjacent territories (radius 100–500 km from sampling points), graminoids pollen grains are recorded in the air only in the third decade of May, while those of wormwoods and goosefoots in the second decade of June (Nenasheva 2013). The second scheme is topsoil sampling at the end of the 2025 growing season. The sampling according to this scheme was implemented only in the steppe zone. Sampling points were selected to cover the most representative sites that encompass the full diversity of zonal, intrazonal, and extrazonal landscapes. Despite the fact that the samples we obtained reflect the pollen spectra over different time periods (Tauber traps cover a single growing season, while soil samples represent the mean pollen spectrum over several last years) and were collected in different years (2022 and 2025), their comparison may well be correct. This is primarily due to the fact that the pollen contribution of each taxon to the spectrum fluctuates from year to year within certain limits determined by the natural zone, location, and vegetation of the sampling point. Therefore, their interannual variability is not stochastic (random) and does not lead to sharp discrete distortions, making the comparison of the 2022 and 2025 sample groups representative for calculating semiquantitative indices. However, to obtain more representative results and subsequently compare them with other studies, we performed separate analyzes of the data obtained for the traps and soil samples. Zonal comparisons were made only for the Tauber trap data.

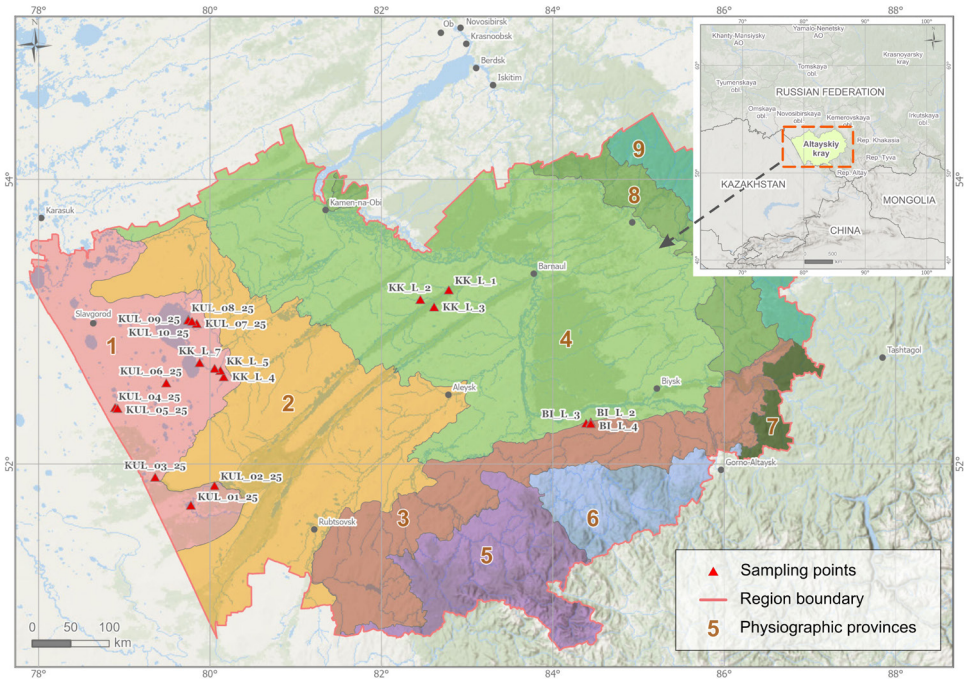


Figure 1. The study area and the location of pollen sampling points. Physiographic provinces: 1 – Kulundinskaya, 2 – Yuzhnoprialeyskaya, 3 – Predaltaiskaya, 4 – Verkhneobskaya, 5 – North-West Altai, 6 – North Altai, 7 – North-East Altai, 8 – Predsalaïrskaya, 9 – Salaïrskaya (Landscape map of Altai Krai 2016).

Table 1. Location of pollen sampling points and landscape characteristics

Point number	Coordinates	Vegetation and location characteristics	Type of sample	Natural zone
Kul-01-25	51,707034 79,777036	Alkaligrass-wormwood-orach (<i>Atriplex</i> + <i>Artemisia</i> + <i>Puccinellia</i>) community in the basin-like depression of the delta of ancient flow gullies	Soil	Steppe
Kul-02-25	51,849232 80,052225	Lichen pine forest at the slightly convex top of the low ridge along the periphery of the delta of ancient flow gullies	Soil	Steppe
Kul-03-25	51,910158 79,359502	Pine forest with dead ground covers in the peripheral part of the delta of ancient flow gullies	Soil	Steppe
Kul-04-25	52,408808 78,893021	Forb sedge (<i>Carex</i>) marshy salt meadow on a low lake terrace	Soil	Steppe
Kul-05-25	52,402634 78,920924	Secondary forb-sedge-feathergrass (<i>Stipa capillata</i> + <i>Carex</i>) solonetzic steppe on a high lake terrace	Soil	Steppe

Point number	Coordinates	Vegetation and location characteristics	Type of sample	Natural zone
Kul-06-25	52,584300 79,489962	Secondary forb-low-bunchgrass-wormwood-feathergrass (<i>Stipa capillata</i> + <i>Artemisia</i>) solonetzic steppe on a lake flat-concave high terrace	Soil	Steppe
Kul-07-25	53,003687 79,845276	Secondary steppe of wormwood-gramineous-feathergrass (<i>Stipa capillata</i>) on the flat summit part of the most drained neoluvial location of the lacustrine-alluvial plain	Soil	Steppe
Kul-08-25	53,033954 79,747210	Halophytic-forb-plantain-salt-peter-wormwood community on a lake low terrace	Soil	Steppe
Kul-09-25	53,027558 79,745841	Licorice-gramineous meadow on a low lake terrace	Soil	Steppe
Kul-10-25	53,019499 79,788887	Currant forb-bushgrass (<i>Calamagrostis epigeios</i>) aspen (<i>Populus tremula</i>) forest in the vast ancient delta of the Kulunda river	Soil	Steppe
KK_L_4	52,627546 80,159872	Birch windbreak on a gently sloping wavy surface (middle part of the slope) of a lacustrine-alluvial plain	Trap	Steppe
KK_L_5	52,672236 80,121981	The wide wavy bottom of the Kuchuk River valley	Trap	Steppe
KK_L_6	52,687157 80,053905	Pine plantings on a flat subplacor surface adjacent to the bench crest of the Kuchuk River valley	Trap	Steppe
KK_L_7	52,726976 79,878692	Cultural vegetation within the boundaries of a summer cottage village on a gentle slope (upper part) of the basin of Lake Kuchukskoye	Trap	Steppe
KK_L_1	53,238928 82,786122	Maple-birch-pine plantings on the low ridge-swale surface of the ancient bottom of the Kasmalinskaya flow gully on the border with the modern valley of the Kasmala river	Trap	Forest-steppe
KK_L_2	53,171669 82,454217	Maple plantings on a gentle, weakly dissected slope (edge part) of the Priobskoye Plato	Trap	Forest-steppe
KK_L_3	53,120015 82,614358	Cultural vegetation within the boundaries of a summer cottage village on a hilly sloped with a low ridge-swale in the ancient peripheral part of the Kasmalinskaya ancient flow gully	Trap	Forest-steppe
BI_L_2	52,306808 84,442802	Maple plantings on a gently sloping wavy surface of the first fluvial terrace above floodplain of the Ob River at the site adjacent to the slope of the Kolyvansky Uval (uval = ridge)	Trap	Forest-steppe

Point number	Coordinates	Vegetation and location characteristics	Type of sample	Natural zone
BI_L_3	52,297009 84,388135	Maple plantings on the steep dissected northern slope (middle part) of the Kolyvansky Uval with modern and ancient landslide forms	Trap	Forest-steppe
BI_L_4	52,294082 84,442854	Maple plantings on the steep dissected northern slope (upper part) of the Kolyvansky Uval with modern and ancient landslide forms	Trap	Forest-steppe

Laboratory sample preparation of the collected samples was carried out according to a modified von Post method (Grichuk & Zaklinskaya 1948) including the following steps: 10% KOH, sieving, HF, 10% HCl. For soil samples with a large number of mineral particles, a heavy liquid KJ + CdJ₂ + H₂O was also used. Microscopic analysis of the prepared samples was performed on a Carl Zeiss Axio Lab A1 light microscope at a magnification of 400 times. Atlases were used for taxonomic identification (Kupriyanova & Aleshina 1972, 1978; Karpovich et al. 2013). For each sample, at least 450 pollen grains were counted, which is considered statistically significant in palynological studies. According to E.D. Zaklinskaya, 150 grains is the minimum number for which the error margins remain the same as for counting larger numbers of grains (Pollen analysis 1950). The sum of pollen from woody and herbaceous taxa was taken as 100%, and the percentage of taxa was calculated relative to this sum. The A/C ratio was calculated as *Artemisia*%/*Chenopodiaceae*%, and the (A + C)/P ratio – (*Artemisia*% + *Chenopodiaceae*%)/*Poaceae*%.

Due to the small sample group size, a combination of statistical methods was used to analyze the calculated ratios. To compare the calculated ratios and subsequently differentiate between zones using pollen trap data installed in the steppe and forest steppe zones, the Mann-Whitney U test was used, because it is optimal for small sample groups. To assess how well the calculated ratios indicate belonging to the steppe or forest-steppe zones, a ROC analysis with Leave-One-Out cross-validation was performed. To examine the relationships between the calculated ratios and climatic parameters (mean annual precipitation (MAP) and mean annual temperature (MAT), we computed the Pearson coefficient and linear regression.

MAP and MAT values were obtained from the WorldClim 2.1 dataset, which presents data for 1970–2000 (Fick & Hijmans 2017). The choice of this particular database is due to its widespread use in palynological research. This data set is a spline interpolation of weather observation data with a spatial resolution of 1 km. Data extraction for each point (based on the sampling location coordinates) was performed in ArcGIS using the Extract Multi Values to Points tool, which assigns the value of the central pixel of the raster layer to each point.

Results

A characteristic feature of the pollen spectra of surface samples of the study area is the presence of pollen from *Artemisia*, Chenopodiaceae, and Poaceae in each sample. Additionally, *Artemisia* and Chenopodiaceae are overrepresented in surface samples compared to their proportion in phytocenoses (Table 2), which may be due to their high pollen productivity and the possibility of wind transfer from adjacent territories. The excessive amount of wormwood pollen has been discussed in other studies (Zhang et al. 2014, 2018). Given that geobotanical descriptions were not carried out at the locations where Tauber traps were set, such conclusions are impossible for these samples. The proportion of *Artemisia* pollen in surface samples from the steppe zone varies from 4.4 to 25.7%, and the proportion of Chenopodiaceae is 1.7 to 51.0%. The proportion of Poaceae pollen in the samples is underestimated compared to the share of graminoids in phytocenoses and fluctuates from 1.2 to 7.4%. In the samples of the Tauber traps installed in the steppe zone, wormwood was detected within 30.6–38.0%, goosefoots – 17.3–24.6%, and graminoids constituted approximately 11.0%. In samples from the forest-steppe zone, a significant increase in graminoids (9.0 to 29.0%) and a decrease in goosefoots (4.6 to 20.0%) were noted. Since the topsoil samples were collected only in the steppe zone, zonal comparisons were made based solely on the results obtained for the Tauber traps.

Table 2. Proportion of *Artemisia*, Chenopodiaceae, and Poaceae (%) in the composition of pollen spectra and phytocenoses (the mean value of the projective cover interval according to the Braun-Blanquet scale) of topsoil sampling points in the steppe zone

Proportion	Kul-01-25	Kul-02-25	Kul-03-25	Kul-04-25	Kul-05-25	Kul-06-25	Kul-07-25	Kul-08-25	Kul-09-25	Kul-10-25
<i>Artemisia</i>										
In the spectrum	13.5	5.6	7.3	4.4	11.6	25.2	25.7	20.5	18.0	12.5
In the phytocenosis	~38	0	0	0	~2	~22	~41	~38	~0.1	0
Chenopodiaceae										
In the spectrum	51.0	2.9	5.5	4.0	10.5	12.1	2.9	12.9	17.8	11.9
In the phytocenosis	~38	0	0	0	0	0	0	0	0	0
Poaceae										
In the spectrum	2.5	1.3	2/3	1.2	4.3	7.4	3.3	5.8	7.3	4.3
In the phytocenosis	~9	0	~0.5	~2	~63	~77	~73	~4	~94	~9

The calculated A/C ratio in topsoil samples ranges from 0.26 to 8.86 (mean 2.03 ± 2.46), while in steppe samples collected using Tauber traps it ranges from 1.27 to 2.19 (mean 1.67 ± 0.43), and in forest steppe it ranges from 1.70 to 4.40 (mean 3.04 ± 1.04). It should be noted that for samples of the same type taken in the steppe and forest-steppe zones, there is a significant overlap of the intervals (Zhao et al. 2012). This A/C ratio is not always indicative for transitional (ecotone) zones such as forest-steppe, where steppe and forest elements interpenetrate (Ma et al. 2017). Therefore, the (A+C)/P ratio was additionally calculated. For the forest-steppe zone, the (A+C)/P ratio, according to Tauber trap data, varies from 1.74 to 3.09 (mean 2.38 ± 0.61); in the steppe zone, this indicator increases on average to 5.24 ± 0.17 . For topsoil samples, this ratio ranges from 4.90 to 25.80 (mean 8.01 ± 6.35), which corresponds to the typical values for steppe regions (Table 3, Fig. 2).

Table 3. Statistical characteristics of the A/C and (A+C)/P ratios for the steppe and forest-steppe regions of Altai Krai

Sample type	Natural zone	Number of samples	Mean $\pm$ SD	Median	Min-Max
A/C ratio					
Topsoil	Steppe	10	2.03 ± 2.46	1.25	0.26–8.86
Tauber trap	Steppe	4	1.67 ± 0.43	1.62	1.27–2.19
	Forest-steppe	6	3.04 ± 1.04	3.12	1.70–4.40
(A+C)/P ratio					
Topsoil	Steppe	10	8.01 ± 6.35	5.72	4.9–25.80
Tauber trap	Steppe	4	5.24 ± 0.17	5.21	5.07–5.46
	Forest-steppe	6	2.38 ± 0.61	2.31	1.74–3.09

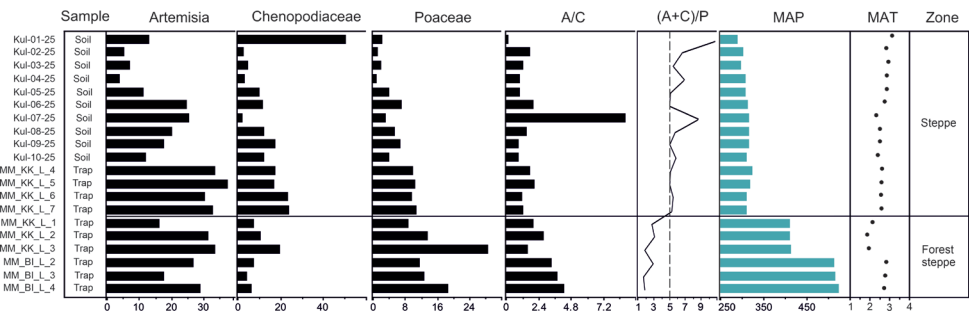


Figure 2. Proportion of *Artemisia*, *Chenopodiaceae* and *Poaceae* (%), A/C and (A+C)/P ratios, mean annual precipitation (MAP, mm), mean annual temperature (MAT, °C), and natural zones.

Although the A/C ratio for points located in forest steppe landscapes indicates steppe landscapes (>1), the (A+C)/P ratio still indicates forest-steppe status $(A+C)/P < 5$ (Fowell et al. 2003, Tables 3, 5). For a more precise zonal delimitation based on the calculated ratios (Tauber traps), we used the Mann–Whitney U test, which is resistant to outliers and optimal for small sample groups. For the A/C ratio, a statistically significant difference is observed ($p=0.04$, $U=6$), but there is significant overlap in the ranges (steppe – 1.27–2.19, foreststeppe – 1.70–4.40), significantly reduces its utility for zonal delimitation. For the ratio $(A + C) / P$, the calculated Mann-Whitney U test ($p=0.002$, $U=0$) indicates complete separation of the sample groups (all values for foreststeppe are lower than all values for the steppe), which makes it a potentially reliable classifier for the steppe and foreststeppe zones for this type of samples located in anthropogenically modified areas. The precision of this classification is also confirmed by the results of the ROC analysis with Leave-One-Out cross-validation based on the ratios for pollen traps (Table 4).

Table 4. The results of the ROC analysis for the calculated ratios based on the Tauber trap data

Ratio	AUC	Sensitivity	Specificity	Overall accuracy, %
A/C	0.83	0.67	0.83	70
(A+C)/P	1.00	1.00	1.00	100

The (A+C)/P ratio excellently differentiates all samples according to their belonging to the steppe and forest steppe zones ($AUC = 1.0$, precision 100%), but the accuracy for the A/C ratio is only 70%. Low specificity (0.83) and accuracy (70%) prevent the calculated A/C ratio from distinguishing zones and significantly limit its independent use as a zonal marker. All this further demonstrates that the (A+C)/P ratio calculated for Tauber traps has a potentially high classification accuracy and can serve as a zonal indicator for this type of sample collected in anthropogenically modified by humans.

Discussion

Analysis of previously calculated data showed that the range of A/C ratios varies between regions, even when samples were collected from the same type of landscape (Table 5). For desert landscapes, this range varies from 0.3 in the Middle East to <1 in Northern and Northwestern China. Based on this, an A/C ratio of <1 is considered the threshold value for desert landscapes. A ratio of >1 is typical for steppe landscapes. For meadows and forests, the A/C ratio is less indicative, as there is a fairly wide range with overlapping values. The value of the ratio $(A+C)/P >5$ indicates arid conditions with steppe vegetation, and values <5 are interpreted as

humid conditions in forest steppes (Fowell et al. 2003). It should be noted that some studies show that these ratios are not universal and their use is limited by a number of factors – anthropogenic load, landscape heterogeneity, and edaphic conditions (Yang & Scuderi 2010, Zhao et al. 2012), which is confirmed by the results of our calculations.

In general, the ratios for different sample types calculated in our studies agree fairly good agreement with previously obtained data for other areas (Table 5). This is particularly evident in steppe areas, especially in topsoil samples. In most cases, our calculated A/C ratio is >1, which is consistent with values for steppe landscapes.

Table 5. A/C ratio in surface samples of different landscape types

Location	Desert	Steppe desert	Steppe	Forest	Meadow	Source
Middle East	<0.3	–	0.2–0.6	–	–	El-Moslimany 1990
Alashan Plateau	<1	>1	>1	–	–	Herzschuh et al. 2004
Eastern Alashan Plateau	<0.5	0.5–2	–	–	–	Li et al. 2005
The northern slope of Tianshan Mountains	<0.5	–	–	–	–	Ji & Liu 2009
Northern and northwestern China	<1	–	>3	–	–	Zhao & Herzschuh 2009
Xinjiang	0.57 (median)	–	1.26 (median)	–	–	Luo et al. 2009
Northeastern Tibetan Plateau	<0.5	0.5–1.4	>1.2	–	–	Wei et al. 2011
Arid and semiarid China	0.62 (mean), 0.47 (median)	3.26 (mean), 1.54 (median)	6.03 (mean), 3.05 (median)	5.08 (mean), 3.47 (median)	2.41 (mean), 3.15 (median)	Zhao et al. 2012

However, in some topsoil samples, the A/C ratio differs significantly from the majority of points. This further confirms the fact that this relationship is not universal and should be used with caution with respect to heterogeneous or anthropogenically modified landscapes. Therefore, the maximum value was obtained for point Kul-07-25 and corresponds to the characteristic values of forest areas – 8.9. It should be noted that at Kul-07-25 the *Artemisia* pollen content (25.7%) is a little lower than the proportion of wormwoods (*Artemisia campestris* L., *A. frigida* Willd., *A. glauca* Pall. ex Willd.) in this community (41%), and in neighboring points the wormwood

pollen content also has close values: Kul-06-25 – 25.2%, Kul-08-25 – 20.5%, Kul-09-25 – 18.0%, Kul-10-25 – 12.5%. At the same time, wormwoods have a significant share in the composition of the Kul-06-25 (22%) and Kul-08-25 (~38%) communities, are found sporadically in Kul-09-25, and are absent in Kul-10-25 (Table 2). Therefore, the high *Artemisia* pollen content in soil samples is primarily due to the regional background (component) and the activity of wind transport from adjacent areas. Furthermore, in the latter two communities, the total projective cover reaches 100%, which may hinder the penetration of airborne pollen into the soil. On the other hand, the proportion of Chenopodiaceae pollen at point Kul-07-25 (2.9%) is 4.2 and more times lower than at the other 4 points under consideration, where it is comparatively stable at points Kul-06-25, Kul-08-25 and Kul-10-25 fluctuating within the range of 11.9 to 12.9%. Only at Kul-09-25 does the Chenopodiaceae pollen content increase to 17.8%, where the licorice-gramineous meadow serves as its unique reservoir, being located in the first strip of closed vegetation behind a sand dune in the path of the prevailing southwest winds, which carry the pollen of goosefoots from the vast salt marshes (solonchaks) of Lake Kulundinskoye. It is likely that the combination of all the factors determines the patterns of pollen deposition patterns in the soil including the anomalously high A/C ratio for the steppe zone at the point Kul-07-25. Despite the fact that this site is located on a fallow land and represents a secondary steppe, we do not have sufficient grounds to assume that the anomalously high A/C ratio for the steppe zone is related to the consequences of anthropogenic impact. The fact is that we do not have an understanding of the mechanism of this impact on the A/C ratio for the reasons discussed above. On the other hand, there is evidence that the A/C ratio should be used with a caution in areas with strong anthropogenic load (Yang & Scuderi 2010, Zhao et al. 2012).

At the point Kul-01-25 located on the boundary between the dry and droughty steppes, the A/C ratio is 0.26, which corresponds to desert areas according to other studies. At this point, the pollen content (13.5%) is typical for the 10 points of the steppe zone, although its projected cover in the community is greater than 30% (Table 2). Such an anomalously low A/C ratio for the steppe zone is due to the extremely high proportion of Chenopodiaceae pollen (51.1%). Firstly, this is the only community of the 10 steppe points where representatives of goosefoots were noted. Secondly, *Atriplex verrucifera* M. Bieb. is the dominant species here with a projective cover 38%, which corresponds to the Chenopodiaceae pollen content of Chenopodiaceae in the soil sample. These communities of salt marshes dominated by goosefoots are the main source of their pollen in the steppe zone and they are even more prevalent in the desert zone. Given the aforementioned lower volatility of Chenopodiaceae pollen compared to *Artemisia*, it can be assumed that most of the Chenopodiaceae pollen is of local origin and was deposited locally. Therefore, the anomalously low A/C ratio for the steppe zone at this point is due to the characteristics of the local community that mimic the vegetation conditions of the desert zone.

Of particular importance when analyzing pollen spectra, including calculated ratios, is the comparison with temperature and mean annual precipitation data, which are key parameters for interpreting pollen spectra. We calculated the Pearson correlation between the calculated A/C and (A+C)/P ratios on the one side, and mean annual precipitation (MAP, mm) and mean annual temperature (MAT, °C) on the other side.

The calculations were performed in two versions according to the sample types: separately for topsoil samples and traps. The correlation analysis for the topsoil samples revealed a weak positive correlation, which did not reach the statistical significance for A/C and MAT ($R^2=0.298$, $p>0.001$), A/C and MAP ($R^2=0.039$, $p>0.001$). The (A+C)/P ratio also correlates quite poorly with the temperature parameters (A+C)/P and MAT ($R^2=0.253$, $p=0.138$). However, the correlation between (A+C)/P and MAP reaches a moderate level ($R^2=0.523$, $p=0.018$) due to outliers at the Kul-01-25 point, while all other values are grouped on the right side of the graph. Thus, insignificant correlations indicate that the calculated ratios in topsoil samples are not influenced by one specific parameter, but by a number of factors (for example, the taphonomy of pollen grains, the influence of melt water, etc.), which must be taken into account when calculating such ratios specifically in topsoil samples.

For the ratios calculated for the Tauber traps, there is a significant positive relationship with the mean annual precipitation. A/C and MAP ($R^2=0.804$, $p<0.001$) (Fig. 3a); for (A+C)/P and MAP, the relationship is slightly weaker ($R^2=0.778$, $p<0.001$) (Fig. 3b), but also reaches high values. No significant correlations with MAT were found: A/C and MAT ($R^2=0.127$, $p>0.001$), (A+C)/P and MAT ($R^2=0.045$, $p>0.001$).

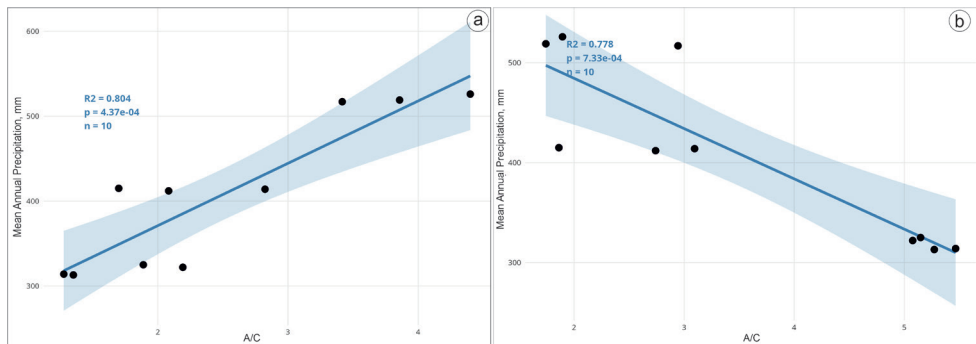


Figure 3. Dependence of the A/C (a) and (A+C)/P (b) ratios on the mean annual precipitation (MAP) for Tauber trap samples.

The positive correlations of the calculated ratios with the mean annual precipitation once again emphasize that the features of sedimentation are important in these calculations. However, within the same landscape type, the relationships between the A/C and (+) / ratios and MAP may not be comparable due to various factors, such as soil salinity, plant community composition, human activity and oth-

ers, which can influence the values of the ratios. Therefore, when interpreting the results, it is necessary to consider various factors (in particular, the sample type) assuming also random and inaccessible ones for study and accounting.

Conclusion

Differences in the $(A+C)/P$ ratio in recent samples collected using Tauber traps in anthropogenically modified plain areas of Altai Krai allow us to potentially divide the territory into steppe and forest steppe zones. This ratio has a positive correlation with the mean annual precipitation, which is due to the sedimentation processes of this type of sample. However, in addition to precipitation, a variety of factors can influence these ratios and must be considered when interpreting the results: the proportion of indicator taxa in the community composition and their pollen productivity, pollen volatility and its ability to persist for a long time, and the influence of vegetation including an anthropogenically modified one on pollen redistribution and deposition.

For topsoil samples, the calculated ratios require a more detailed study with a larger number of replications from different locations.

Our data and other studies confirm that the A/C and $(A+C)/P$ ratios can be used to detect vegetation changes and serve as qualitative or semi-quantitative indicators of moisture in the steppe and forest-steppe landscapes of Altai Krai but require uniform sample groups and a larger number of collected samples to minimize error. More research is needed on the relationship between the calculated ratios and climatic parameters, as well as the feasibility of using this ratio for different sample types and various natural zones (for example, topsoil samples in forest steppe landscapes). We believe that the pollen ratio is a very promising tool for biome paleoreconstruction based on the principle of actualism, as it unifies and formalizes pollen content data in samples, allowing us to better understand the mechanisms by which vegetation is reflected in recent and fossil pollen spectra.

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