SUPPLEMENTARY: Rate-of-change analysis in palaeoecology revisited: a new approach

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SUPPLEMENTARY

Supplementary Methods

Detailed description of R-Ratepol:

Randomisation

Due to the inherent statistical errors in a pollen count in each level (Birks & Gordon, 1985) and uncertainties in the age estimates for each level from age-depth modelling, R-Ratepol is run several times and the results summarised. For each run, one age prediction is randomly selected from the pool of age predictions, and pollen taxa are standardised to a certain number of pollen grains in each working unit (WU) by rarefaction (using random sampling without replacement to a default of 150 pollen grains). The calculation between two consecutive WUs (i.e. one working-unit combination) results in a **RoC score** and a **time position** (calculated as the mean age position of the WUs). However, due to random sampling of the age sequence, each WU combination will result in multiple RoC values and age positions. R-Ratepol assigns the age position of each WU combination as the median time position from all calculations. The final RoC values are calculated as the median and 95th quantile of the scores from all calculations. In addition, because of excluding empty bins in the selective binning with a moving window approach, it is possible that some WU combinations will not be present in some calculations. Therefore, R-Ratepol only includes WU combinations that are present in at least 10% of all calculations.

Description of individual steps:

1) Pollen-data smoothing
Each pollen taxon is smoothed by one of five smoothing functions in R-Ratepol.

A) None: Pollen data are not smoothed

B) Moving average (Wilkinson, 2005): Each focus value is calculated as the average over N number of levels (preferably ½ N before and ½ after the focus level; values are adjusted at the beginning and end of the core. N must be odd number). Note that each calculation is done from scratch and results are saved separately in order to avoid cumulative rounding errors. Default N is set to 5.

C) Grimm's smoothing (Grimm & Jacobson, 1992): Similar to a moving average but N is not fixed. For each level, N is selected as an odd number between N_a and N_b ($N \subset \{N_a, N_b\}$) while maintaining the maximum age difference from the selected levels as Age_{MAX}. Default values are set as N_a= 5, N_b = 9, Age_{MAX} = 500.

D) Age-weighted average (Wilkinson, 2005): Similar to the moving average above but the average is weighted by the age difference from the focus level and multiplied by $\frac{1}{\mathrm{CONSTANT}}$

(CONSTANT is selected by the user). To avoid up-weighting levels, if $\frac{\mathrm{CONSTANT}}{AGEDIFF}$ exceeds 1, it is treated as 1. This means that levels closer than the CONSTANT to the target age are given full weight, but those farther away are downweighted by an amount increasing with age difference. CONSTANT has a default setting of 500 years.

E) Shepard's 5-term filter (Davis, 1986; Wilkinson, 2005): Smoothing over 5 points following the equation below

$$\mathrm{V}_{NEW} = \frac{17*\mathrm{V} + 12*(\mathrm{V}_{(+1)} + \mathrm{V}_{(-1)}) - 3*(\mathrm{V}_{(+2)} + \mathrm{V}_{(-2)})}{35},$$

where V is the focal level value. All result values smaller than zero are treated as zero.

2) Creation of template for all time bins in all window movement

Bins of selected size are created, starting from zero. This is repeated many times, with each time bin (window) shifting by Z years forward. This is repeated X times, where X = bin size / Z.

3a) Random-time sequence sampling from the age-depth model

One age sequence is randomly selected from the 1000 sequences generated from the *Bchron* age-depth models. Each of the levels is given one age value and the correct temporal order is checked in the sequence.

3b) Creation of working units (WUs) and data standardisation

RoC can be calculated between individual levels or bins. In terms of calculation between levels, each level becomes one WU. If bins are selected, the level closest to the start of each bin is selected as representative of that bin. All other levels are excluded. Bins with valid levels become the new WUs, and empty bins are excluded. Each WU is standardised to the same number of pollen grains (default value = 150), using random sampling of pollen grains without replacement. The dataset is reduced by excluding all WUs lacking any pollen, all pollen taxa with no counts.

3c) Calculate RoC between adjacent WUs

First, the dissimilarity coefficient between adjacent WUs is calculated using one of four dissimilarity coefficients (Prentice, 1980):

A) Euclidean distance:

$\sqrt{\sum_{i=1}^{m}(A_i - B_i)^2}$, where A_i and B_i are relative pollen values (percentages or proportions) for WUs A and B of taxon i, and there are *m* taxa.

B) Standardised Euclidean distance:

$\sqrt{\sum_{i=1}^{m}(\frac{A_i - B_i}{SD_i})^2}$, where A_i and B_i are relative pollen values for WUs A and B of taxon i, SD_i is the standard deviation for taxon i calculated from the whole sequence, and there are *m* taxa.

C) Chord distance:

$\sqrt{\sum_{i=1}^{m}(\sqrt{A_i}-\sqrt{B_i})^2}$, where A_i and B_i are relative pollen values for WUs A and B of taxon i, and there are *m* taxa.

D) Chi-squared coefficient:

$\sqrt{\sum_{i=1}^{m}\frac{(A_i-B_i)^2}{(A_i+B_i)}}$, where A_i and B_i are relative pollen values for WUs A and B of taxon i , and there are *m* taxa.

Next, the age difference between subsequent WUs is calculated. Finally, the RoC score between WUs is calculated as:

$RoC_{A-B} = \frac{DC_{A-B} * Age.diff_{mean}}{Age.diff_{A-B}}$, where DC_{A-B} is the dissimilarity between WUs A and B, $Age.diff_{mean}$ is the average age difference between WUs in the whole sequence, and $Age.diff_{A-B}$ is the age difference between WUs A and B.

3d) Summarisation of results from all moving windows

Bins (windows) are moved forward by a selected amount of time Z, the steps 3a–3c are repeated for a new set of WUs (age sampling, levels selection, RoC calculation). This is repeated X times, where $X = \frac{BIN\ size}{Z}$. Results from all window positions are merged and saved as a single value.

4) Step 3 is repeated X times, with a default number of 10,000 repetitions

5) Validation and summary of results from all randomisations

Results from all randomisations are merged while keeping the identity of each WU combination. Due to random selection of the age sequence, each of the WU combinations will result in multiple RoC values and time positions. The time position of each WU combination is assigned as the median of the time positions from all randomisations. Final RoC values are calculated as the median score of all randomisations. In addition, due to excluding empty bins in selective binning with a moving window, there is a chance that some WU combinations will be present only in some randomisations. Therefore, only WU combinations that are present in at least 10% of all randomisations are retained.

5) Data beyond the selected age are excluded (8000 cal yr BP in this study)

6) Detection of significant peak-points

R-Ratepol detects peak-points using one of three methods:

1) Threshold method: Each point in the RoC sequence is compared to a median of all RoC scores from the whole (i.e. *threshold value*). The point is considered significant if the 95th quantile of the RoC scores from all calculations is higher than the *threshold value*.
2) GAM method: A GAM is fitted through the RoC scores and time positions ($\mathrm{GAM} = \mathrm{RoC} \sim \mathrm{s}(\mathrm{time}, k = 3)$). The distance between each point and the fitted value is calculated. A peak-point is considered significant if the distance between the point and the fitted GAM is greater than 1.5 * the standard deviation of all differences.
3) Signal-to-Noise Index (SNI) method: We adapted SNI from Kelly *et al.* (2011) developed to detect changes in charcoal stratigraphical records. SNI is calculated for the whole RoC sequence and a peak-point is considered significant if it has an SNI value higher than 3 with the GAM set as a reference value and with a time window of 500 yrs.

Supplementary Tables and Figures

Table S1. AIC results in terms of successful detection of peak-points comparing different WU selection methods. We fitted $\text{glmmTMB}_{success-method}$ with the ratio of levels marked as peak-points to all levels at the focal area ($R_{success-method}$) as the dependent variable with a beta-binomial error distribution. Independent variables were: WU (3 level factor), Peak-point detection method (3 level factor), position of environmental change (i.e. density of levels; 2 level factor), richness of dataset (2 level factor), and all their interactions. Individual dataset ID was selected as the random factor. We used *dredge* to calculate all possible combinations of models and ordered them by AICc. Plus-symbol (+) indicates that the predictor is included in the model.

Richness	Peak	Position	WU	Richness: Peak	Richness: Position	Richness:WU	Peak:Position	Peak:WU	Position:WU	Richness: Peak:Position	Richness: Peak:WU	Richness:Position:WU	Peak:Position:WU	Richness: Peak:Position:WU	df	logLik	AICc
+	+	+	+	+	+	+	+	+	+	+	+	+	+		39	-20478.7	41035.46
+	+	+	+	+	+	+	+	+	+	+	+		+		37	-20483.1	41040.21
+	+	+	+	+	+	+	+	+	+		+	+	+		37	-20484.7	41043.53
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	43	-20478.9	41043.93
+	+	+	+	+		+	+	+	+		+		+		34	-20488.5	41044.98
+	+	+	+	+	+	+	+	+	+		+		+		35	-20490.4	41050.92
+	+	+	+	+	+	+	+	+	+	+		+	+		35	-20496.1	41062.26
+	+	+	+		+	+	+	+	+			+	+		31	-20500.3	41062.55
+	+	+	+	+	+	+	+	+	+			+	+		33	-20499.9	41065.91
+	+	+	+		+	+	+	+	+				+		29	-20508.2	41074.35
+	+	+	+	+	+	+	+	+	+	+			+		33	-20506.3	41078.64
+	+	+	+	+		+	+	+	+				+		30	-20509.4	41078.86
+	+	+	+			+	+	+	+				+		28	-20511.7	41079.45
+	+	+	+	+	+	+	+	+	+				+		31	-20509.1	41080.18
+	+	+	+	+	+		+	+	+	+			+		31	-20511.7	41085.44
+	+	+	+	+			+	+	+				+		28	-20516.5	41088.98
+	+	+	+		+		+	+	+				+		27	-20518.5	41090.96
+	+	+	+	+	+		+	+	+				+		29	-20516.7	41091.42
+	+	+	+				+	+	+				+		26	-20520.1	41092.32
	+	+	+				+	+	+				+		25	-20521.9	41093.81
+	+	+	+	+	+	+	+	+	+	+	+	+			35	-20957.3	41984.62
+	+	+	+	+	+	+	+	+	+		+	+			33	-20960.6	41987.32
+	+	+	+	+	+	+	+	+	+	+	+				33	-20962.0	41990.11
+	+	+	+	+		+	+	+	+		+				30	-20966.7	41993.51

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	+	+					+								13	-21968.9	43963.74
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+	+	+	+	+		+									18	-22261.0	44558.03
+	+	+	+	+	+	+									19	-22260.6	44559.19
+	+	+	+			+									16	-22263.6	44559.22
+	+	+	+	+											16	-22266.3	44564.59
+	+	+	+	+	+										17	-22265.8	44565.59
+	+	+	+		+										15	-22268.6	44567.26
+	+	+	+												14	-22270.2	44568.45
+	+	+													12	-22393.2	44810.32
	+	+													11	-22394.8	44811.61
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	+		+					+							16	-23446.3	46924.53
+	+		+					+							17	-23445.7	46925.40
+	+		+	+											15	-23794.1	47618.17
+	+		+			+									15	-23794.6	47619.22
+	+		+	+		+									17	-23792.9	47619.71
+	+		+												13	-23801.0	47627.93
	+		+												12	-23803.2	47630.33
	+														10	-23925.6	47871.12
+		+	+		+	+			+			+			19	-42745.3	85528.71
+		+	+			+			+						16	-42752.0	85536.03
+		+	+		+				+						15	-42756.0	85542.05
+		+	+			+									14	-42985.3	85998.61
+		+	+												12	-42987.6	85999.29
+		+	+		+	+									15	-42986.9	86003.77
		+	+												11	-42992.5	86006.93
+		+	+		+										13	-42990.8	86007.54
+		+													10	-43101.4	86222.78
		+													9	-43104.1	86226.29
+		+			+										11	-43102.8	86227.60
															8	-43893.0	87802.03

Table S2. AIC results in terms of false positives of peak-points comparing different WU selection methods. We fitted $\mathrm{glmmTMB}_{FalsePositive-method}$ with the ratio of levels marked as peak-points to all levels at the time of manual edit of the environmental data ($R_{FalsePositives-method}$) as the dependent variable with a beta-binomial error distribution. Independent variables were: WU (3 level factor), peak-point detection method (3 level factor), position of environmental change (i.e. density of levels; 2 level factor), richness of dataset (2 level factor), and all their interactions. Individual dataset ID was selected as the random factor. We used *dredge* to calculate all possible combinations of models and ordered them by AICc. Plus-symbol (+) indicates that the predictor is included in the model.

Diversity	Peak	Position	WU	Diversity: Peak	Diversity: Position	Diversity:WU	Peak:Position	Peak:WU	Position:WU	Diversity: Peak:Position	Diversity: Peak:WU	Diversity: Position:WU	Peak:Position:WU	Diversity: Peak:Position:WU	df	logLik	AICc
+	+	+	+				+	+	+				+		26	-17158.7	34369.41
	+	+	+				+	+	+				+		25	-17160.0	34369.96
+	+	+	+	+	+		+	+	+	+			+		31	-17154.1	34370.22
+	+	+	+	+	+	+	+	+	+	+	+	+	+		39	-17146.9	34371.92
+	+	+	+	+		+	+	+	+		+		+		34	-17152.1	34372.23
+	+	+	+		+		+	+	+				+		27	-17159.2	34372.38
+	+	+	+	+	+	+	+	+	+		+	+	+		37	-17150.5	34374.96
+	+	+	+	+			+	+	+				+		28	-17159.6	34375.22
+	+	+	+			+	+	+	+				+		28	-17159.8	34375.57
+	+	+	+		+	+	+	+	+				+		29	-17159.1	34376.29
+	+	+	+	+	+	+	+	+	+		+		+		35	-17153.4	34376.82
+	+	+	+	+	+		+	+	+				+		29	-17160.2	34378.49
+	+	+	+	+		+	+	+	+				+		30	-17159.3	34378.59
+	+	+	+		+	+	+	+	+			+	+		31	-17158.8	34379.59
+	+	+	+	+	+	+	+	+	+				+		31	-17158.8	34379.67
+	+	+	+	+	+		+	+	+	+					27	-17172.8	34399.67
+	+	+	+	+	+	+	+	+	+	+	+	+			35	-17165.7	34401.38
	+	+	+				+	+	+						21	-17181.2	34404.46
+	+	+	+	+	+	+	+	+	+	+		+			31	-17171.3	34404.70
+	+	+	+	+			+	+	+						24	-17179.0	34406.03
+	+	+	+	+		+	+	+	+		+				30	-17173.1	34406.31
+	+	+	+			+	+	+	+						24	-17179.3	34406.61
+	+	+	+	+	+	+	+	+	+		+				31	-17172.6	34407.15
+	+	+	+	+	+	+	+	+	+		+	+			33	-17170.8	34407.66
+	+	+	+				+	+	+						22	-17182.0	34407.94
+	+	+	+		+	+	+	+	+			+			27	-17177.0	34408.06
+	+	+	+	+		+	+	+	+						26	-17178.9	34409.76

+	+	+	+	+	+	+	+	+	+						27	-17178.6	34411.31
+	+	+	+	+	+	+	+	+	+			+			29	-17176.7	34411.46
+	+	+	+		+		+	+	+						23	-17182.8	34411.56
+	+	+	+		+	+	+	+	+						25	-17181.7	34413.52
+	+	+	+	+	+		+	+	+						25	-17182.9	34415.87
+	+	+	+				+	+							20	-17240.9	34521.86
+	+	+	+	+	+	+	+	+		+	+				31	-17230.4	34522.79
+	+	+	+	+	+		+	+		+					25	-17236.7	34523.47
	+	+	+				+	+							19	-17244.0	34526.00
+	+	+	+	+	+	+	+	+		+					27	-17236.7	34527.46
+	+	+	+			+	+	+							22	-17242.0	34527.97
+	+	+	+		+		+	+							21	-17243.3	34528.67
+	+	+	+		+	+	+	+							23	-17242.6	34531.14
+	+	+	+	+		+	+	+			+				28	-17237.6	34531.19
+	+	+	+	+	+		+	+							23	-17243.9	34533.78
+	+	+	+	+	+	+	+	+			+				29	-17239.6	34537.16
+	+	+	+	+		+	+	+							24	-17247.3	34542.53
	+	+	+				+		+						17	-17589.8	35213.68
+	+	+	+	+			+		+						20	-17591.3	35222.57
+	+	+	+	+		+	+		+						22	-17591.3	35226.55
+	+	+		+	+		+			+					19	-17831.3	35700.59
+	+	+					+								14	-17838.0	35704.06
+	+	+		+			+								16	-17837.5	35707.03
+	+	+	+	+	+	+	+			+					23	-17830.8	35707.57
+	+	+		+	+		+								17	-17837.0	35708.09
+	+	+	+		+		+								17	-17837.4	35708.85
+	+	+	+	+			+								18	-17837.4	35710.80
+	+	+	+		+	+	+								19	-17837.3	35712.65
+	+	+	+	+	+	+	+								21	-17837.0	35716.10
+	+	+	+					+	+						20	-18751.2	37542.41
+	+	+	+	+		+		+	+		+				28	-18744.6	37545.23
+	+	+	+			+		+	+						22	-18750.7	37545.44
+	+	+	+	+	+	+		+	+		+	+			31	-18742.3	37546.66
+	+	+	+	+	+			+	+						23	-18750.4	37546.80
+	+	+	+	+		+		+	+						24	-18750.8	37549.53
+	+	+	+	+	+	+		+	+			+			27	-18748.2	37550.43
+	+	+	+	+	+	+		+	+						25	-18750.8	37551.69
+	+	+	+	+	+	+		+	+		+				29	-18748.7	37555.39
+	+	+	+		+	+		+							21	-18990.5	38023.01
+	+	+	+	+	+			+							21	-18991.1	38024.29
+	+	+	+	+	+	+		+			+				27	-18985.9	38025.78
+	+	+	+	+		+		+							22	-18991.3	38026.59
+	+		+	+				+							19	-19049.0	38136.08
+	+		+	+		+		+			+				25	-19043.2	38136.35

+	+		+	+		+		+							21	-19048.9	38139.91
+	+	+	+	+	+	+			+						21	-19323.4	38688.80
+	+	+		+	+										15	-19547.9	39125.81
+	+	+	+												14	-19550.2	39128.44
+	+	+	+	+											16	-19549.6	39131.13
+	+	+	+			+									16	-19549.8	39131.60
+	+	+	+	+		+									18	-19548.1	39132.21
+	+	+	+	+	+	+									19	-19549.0	39135.92
+	+														11	-19606.7	39235.46
	+														10	-19608.1	39236.23
+	+			+											13	-19606.8	39239.65
+		+	+						+						14	-27510.5	55048.94
+		+	+			+			+						16	-27509.8	55051.63
+		+	+		+	+			+						17	-27510.0	55054.02
+		+			+										11	-27685.0	55392.02
		+	+												11	-27686.0	55394.01
+		+	+												12	-27685.5	55395.01
+		+	+			+									14	-27685.4	55398.90
+		+	+		+	+									15	-27684.9	55399.81
															8	-27727.8	55471.52
+			+			+									13	-27729.1	55484.15

Table S3. AIC results in terms of successful detection of peak-points using binning with moving window method and GAM peak-point detection methods. We fitted $\mathrm{glmmTMB}_{success-settings}$ with $R_{success-settings}$ dependent variable respectively with beta-binomial error distribution. Independent variables were: smoothing type (5 level factor), dissimilarity coefficient (4 level factor), position of environmental change (i.e. density of levels; 2 level factor), richness of dataset (2 level factor), and all their interactions. Individual dataset ID was selected as the random factor. We used *dredge* to calculate all possible combination of models and order them by AICc. Plus-symbol (+) indicates that the predictor is included in the model.

DC	Richness	Position	Smooth	DC:Richness	DC:Position	DC:Smooth	Richness: Position	Richness: Smooth	Position: Smooth	DC:Richness:Position	DC:Richness: Smooth	DC:Position: Smooth	Richness: Position: Smooth	DC:Richness:Position: Smooth	df	logLik	AICc
+	+	+	+		+		+	+	+				+		28	-2972.51	6001.226
+	+	+	+				+	+	+				+		25	-2975.59	6001.334
+	+	+	+	+	+		+	+	+	+			+		34	-2967.05	6002.392
+	+	+	+	+	+		+	+	+				+		31	-2970.10	6002.443

+	+	+	+	+			+	+	+				+		28	-2973.27	6002.736
	+	+	+				+	+	+				+		22	-2980.85	6005.824
+	+	+	+		+		+		+						20	-2982.92	6005.942
+	+	+	+				+		+						17	-2986.15	6006.369
+	+	+	+	+	+		+		+						23	-2980.73	6007.590
+	+	+	+	+	+		+		+	+					26	-2977.78	6007.739
+	+	+	+	+			+		+						20	-2983.85	6007.808
+	+	+	+		+	+	+	+	+				+		40	-2963.92	6008.251
+	+	+	+	+	+				+						22	-2982.27	6008.668
+	+	+	+	+					+						19	-2985.33	6008.745
+	+	+	+	+	+	+	+	+	+				+		43	-2961.52	6009.519
+	+	+	+			+	+	+	+				+		37	-2967.63	6009.623
+	+	+	+	+	+	+	+	+	+	+			+		46	-2958.75	6010.037
+	+	+	+		+		+	+	+						24	-2981.16	6010.479
	+	+	+				+		+						14	-2991.43	6010.906
+	+	+	+	+		+	+	+	+				+		40	-2965.37	6011.153
	+	+	+						+						13	-2992.86	6011.759
+	+	+	+	+	+		+	+	+						27	-2978.81	6011.804
+	+	+	+	+	+		+	+	+	+					30	-2975.81	6011.844
+	+	+	+	+			+	+	+						24	-2981.93	6012.009
+		+	+		+				+						18	-2988.35	6012.795
+		+	+						+						15	-2991.42	6012.903
+	+	+	+		+			+	+						23	-2983.40	6012.941
+	+	+	+		+	+	+		+						32	-2974.48	6013.224
+	+	+	+		+	+	+	+	+			+	+		52	-2954.55	6013.798
+	+	+	+		+	+			+						31	-2975.93	6014.106
+	+	+	+	+				+	+						23	-2984.15	6014.444
+	+	+	+	+	+	+	+		+						35	-2972.08	6014.486
+	+	+	+	+	+			+	+						26	-2981.17	6014.524
+	+	+	+			+	+		+						29	-2978.20	6014.612
+	+	+	+	+	+	+	+		+	+					38	-2969.18	6014.732
+	+	+	+	+	+	+	+	+	+			+	+		55	-2952.06	6014.886
	+	+	+				+	+	+						18	-2989.50	6015.081
+	+	+	+	+	+	+	+	+	+	+		+	+		58	-2949.11	6015.089
+	+	+	+			+			+						28	-2979.63	6015.458
+	+	+	+	+	+	+			+						34	-2973.62	6015.548
+	+	+	+	+		+	+		+						32	-2975.85	6015.969
+	+	+	+	+		+			+						31	-2977.34	6016.920
		+	+						+						12	-2996.69	6017.425
+	+	+	+		+	+	+	+	+						36	-2972.57	6017.469
+	+	+	+	+	+	+	+	+	+						39	-2970.16	6018.713
+	+	+	+			+	+	+	+						33	-2976.28	6018.835
+	+	+	+		+	+	+		+			+			44	-2965.21	6018.918
+	+	+	+	+	+	+	+	+	+	+					42	-2967.24	6018.936

+	+	+	+		+	+			+			+			43	-2966.67	6019.816
+		+	+		+	+			+						30	-2979.80	6019.829
+	+	+	+		+	+		+	+						35	-2974.80	6019.919
+	+	+	+	+	+	+	+		+			+			47	-2962.82	6020.215
+	+	+	+	+		+	+	+	+						36	-2973.95	6020.241
+	+	+	+	+	+	+	+		+	+		+			50	-2960.01	6020.654
+	+	+	+	+	+	+			+			+			46	-2964.35	6021.235
+	+	+	+			+		+	+						32	-2978.49	6021.246
+		+	+			+			+						27	-2983.53	6021.249
+	+	+	+	+	+	+		+	+						38	-2972.50	6021.382
+	+	+	+	+		+		+	+						35	-2976.22	6022.752
+	+	+	+		+	+	+	+	+			+			48	-2963.26	6023.115
+	+	+	+	+	+	+	+	+	+			+			51	-2960.88	6024.423
+	+	+	+	+	+	+	+	+	+	+		+			54	-2958.04	6024.832
+		+	+		+	+			+			+			42	-2970.52	6025.494
+	+	+	+		+	+		+	+			+			47	-2965.56	6025.679
+	+	+	+	+	+	+		+	+			+			50	-2963.24	6027.122
+	+	+	+	+	+	+	+	+	+		+		+		55	-2960.12	6031.009
+	+	+	+	+	+	+	+	+	+	+	+		+		58	-2957.15	6031.169
+	+	+	+	+		+	+	+	+		+		+		52	-2964.04	6032.779
+	+	+	+	+	+	+	+	+	+	+	+	+	+		70	-2947.45	6036.148
+	+	+	+	+	+	+	+	+	+		+	+	+		67	-2950.68	6036.504
+	+	+	+	+	+	+	+	+	+		+				51	-2968.77	6040.217
+	+	+	+	+	+	+	+	+	+	+	+				54	-2965.77	6040.282
+	+	+	+	+		+	+	+	+		+				48	-2972.60	6041.782
+	+	+	+	+	+	+		+	+		+				50	-2971.14	6042.916
+	+	+	+	+		+		+	+		+				47	-2974.86	6044.279
+	+	+	+	+	+	+	+	+	+		+	+			63	-2959.41	6045.843
+	+	+	+	+	+	+	+	+	+	+	+	+			66	-2956.50	6046.120
+	+	+	+	+	+	+		+	+		+	+			62	-2961.88	6048.746
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	82	-2942.35	6050.413
+	+	+	+		+		+								16	-3101.31	6234.691
+	+	+	+												12	-3105.58	6235.198
+	+	+	+		+										15	-3102.68	6235.419
+	+	+	+	+			+								16	-3102.00	6236.075
+	+	+	+	+	+		+								19	-3099.02	6236.130
+	+	+	+	+	+		+			+					22	-3096.19	6236.515
+	+	+	+	+											15	-3103.43	6236.918
+	+	+	+	+	+										18	-3100.51	6237.103
	+	+	+				+								10	-3109.38	6238.797
+		+	+												11	-3109.35	6240.733
+	+	+	+				+	+							17	-3103.41	6240.899
+	+	+	+		+	+	+								28	-3092.73	6241.656
+	+	+	+					+							16	-3104.82	6241.699

+	+	+	+			+	+								25	-3095.80	6241.759
+	+	+	+		+			+							19	-3101.87	6241.843
+	+	+	+		+	+									27	-3094.11	6242.408
+	+	+	+	+			+	+							20	-3101.21	6242.517
+	+	+	+			+									24	-3097.19	6242.537
+	+	+	+	+	+		+	+							23	-3098.22	6242.579
+	+	+	+	+	+		+	+		+					26	-3095.38	6242.934
+	+	+	+	+	+	+	+								31	-3090.38	6243.017
+	+	+	+	+		+	+								28	-3093.57	6243.354
+	+	+	+	+				+							19	-3102.63	6243.363
+	+	+	+	+	+			+							22	-3099.65	6243.419
+	+	+	+	+	+	+									30	-3091.89	6244.007
+	+	+	+	+		+									27	-3094.98	6244.154
		+	+												8	-3114.47	6244.968
	+	+	+				+	+							14	-3108.56	6245.175
	+	+	+					+							13	-3109.94	6245.931
+		+	+		+	+									26	-3097.86	6247.891
+	+	+	+		+	+	+	+							32	-3091.91	6248.077
+	+	+	+			+	+	+							29	-3095.00	6248.218
+	+	+	+		+	+		+							31	-3093.29	6248.821
+	+	+	+			+		+							28	-3096.39	6248.983
+	+	+	+	+	+	+	+	+							35	-3089.60	6249.517
+	+	+	+	+		+	+	+							32	-3092.78	6249.828
+	+	+	+	+	+	+	+	+		+					38	-3086.78	6249.924
+	+	+	+	+	+	+		+							34	-3091.10	6250.501
+	+	+	+	+		+		+							31	-3094.18	6250.606
+	+	+	+	+	+	+	+	+			+				47	-3088.18	6270.926
+	+	+	+	+		+	+	+			+				44	-3091.31	6271.110
+	+	+	+	+	+	+	+	+		+	+				50	-3085.32	6271.289
+	+	+	+	+	+	+		+			+				46	-3089.65	6271.847
+	+	+	+	+		+		+			+				43	-3092.74	6271.947
+	+	+					+								9	-3130.92	6279.870
+	+	+			+		+								12	-3128.11	6280.264
+	+	+													8	-3132.41	6280.835
+	+	+			+										11	-3129.49	6281.004
+	+	+		+			+								12	-3128.86	6281.766
+	+	+		+	+		+								15	-3125.86	6281.776
+	+	+		+	+		+			+					18	-3123.03	6282.137
+	+	+		+											11	-3130.29	6282.613
+	+	+		+	+										14	-3127.34	6282.734
	+	+					+								6	-3136.09	6284.189
+		+													7	-3136.15	6286.318
+		+			+										10	-3133.20	6286.422
		+													4	-3141.23	6290.473

+	+		+												11	-3521.13	7064.301
+	+		+	+											14	-3519.15	7066.357
	+		+												8	-3525.74	7067.502
+			+												10	-3524.51	7069.048
+	+		+					+							15	-3520.43	7070.912
			+												7	-3529.13	7072.276
+	+		+	+				+							18	-3518.46	7073.004
+	+		+			+									23	-3513.47	7073.085
	+		+					+							12	-3525.03	7074.107
+	+		+	+		+									26	-3511.48	7075.135
+			+			+									22	-3516.83	7077.793
+	+		+			+		+							27	-3512.74	7079.661
+	+		+	+		+		+							30	-3510.76	7081.761
+	+		+	+		+		+			+				42	-3509.47	7103.394
+	+														7	-3545.24	7104.489
+	+			+											10	-3543.3	7106.63
	+														4	-3549.83	7107.657
+															6	-3548.64	7109.292
															3	-3553.19	7112.384

Table S4. AIC results in terms of false positives of peak-points using binning with a moving window method and the GAM peak-point detection methods. We fitted glmmTMB $_{FalsePosite-settings}$ with $R_{FalsePositve-settings}$ as dependent variable with a beta-binomial error distribution. Independent variables were: smoothing type (5 level factor), dissimilarity coefficient (4 level factor), position of environmental change (i.e. density of levels; 2 level factor), richness of dataset (2 level factor), and all their interactions. Individual dataset ID was selected as the random factor. We used *dredge* to calculate all possible combination of models and ordered them by AICc. Plus-symbol (+) indicates that the predictor is included in the model.

DC	Diversity	Position	Smooth	DC:Diversity	DC:Position	DC:Smooth	Diversity:Position	Diversity:Smooth	Position:Smooth	DC:Diversity:Position	DC:Diversity:Smooth	DC:Position:Smooth	Diversity:Position: Smooth	DC:Diversity:Position:Smooth	df	logLik	AICc
+	+	+	+				+		+						17	-825.104	1684.284
	+	+	+				+		+						14	-828.397	1684.846
+	+	+	+				+								13	-830.126	1686.298
		+	+						+						12	-831.255	1686.550
+	+	+	+						+						16	-827.749	1687.565
+		+	+												11	-833.052	1688.137

		+	+												8	-836.302	1688.622
+	+	+	+												12	-832.749	1689.537
	+	+	+												9	-836.089	1690.201
+		+	+		+				+						18	-827.533	1691.151
+	+	+	+		+		+								16	-829.679	1691.427
+	+	+	+		+				+						19	-827.304	1692.703
+		+	+		+										14	-832.471	1692.995
+	+	+	+	+					+						19	-827.702	1693.498
+	+	+	+				+	+							17	-829.850	1693.777
+	+	+	+					+	+						20	-827.436	1694.977
+	+	+	+	+	+		+		+						23	-824.591	1695.321
+	+	+	+	+											15	-832.652	1695.365
+	+	+	+					+							16	-832.481	1697.030
	+	+	+					+							13	-835.719	1697.483
+	+	+	+		+		+	+							20	-829.327	1698.760
+	+	+	+	+			+	+							20	-829.744	1699.593
+	+	+	+	+	+										18	-832.194	1700.473
+	+	+	+	+				+							19	-832.415	1702.925
+	+	+	+	+	+		+			+					22	-829.689	1703.505
+		+	+			+			+						27	-825.377	1704.943
+	+	+	+	+			+	+	+				+		28	-824.659	1705.521
+		+	+			+									23	-830.575	1707.289
+	+	+	+	+	+		+	+	+				+		31	-824.196	1710.641
+		+	+		+	+									26	-829.918	1712.012
+	+	+	+	+		+									27	-830.175	1714.540
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+	+	+	+	+		+	+	+							32	-827.049	1718.363
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+	+	+	+	+	+	+	+	+							35	-826.810	1723.937
+	+	+	+	+		+	+	+	+				+		40	-821.988	1724.388
+	+	+	+		+	+	+		+			+			44	-819.507	1727.511
+	+	+	+	+		+	+	+			+				44	-826.011	1740.519
+	+	+	+	+		+		+			+				43	-828.485	1743.445
+	+	+	+	+	+	+		+			+				46	-828.292	1749.127
+	+	+					+								9	-980.765	1979.554
+		+													7	-983.648	1981.311
		+													4	-986.761	1981.527
	+	+													5	-986.412	1982.832
+	+	+													8	-983.429	1982.875
+	+	+			+		+								12	-980.326	1984.691
+		+			+										10	-983.190	1986.407
+	+	+			+										11	-982.953	1987.939
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+			+												10	-1070.99	2162.016

			+												7	-1074.00	2162.022
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+	+		+	+											14	-1070.70	2169.460
+	+		+					+							15	-1070.47	2170.996
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+	+		+			+									23	-1068.17	2182.488
+	+		+			+		+							27	-1067.85	2189.882
+	+		+	+		+		+							30	-1067.69	2195.610
+															6	-1215.88	2443.767
	+														4	-1218.64	2445.277
+	+														7	-1215.69	2445.401
+	+			+											10	-1215.62	2451.277

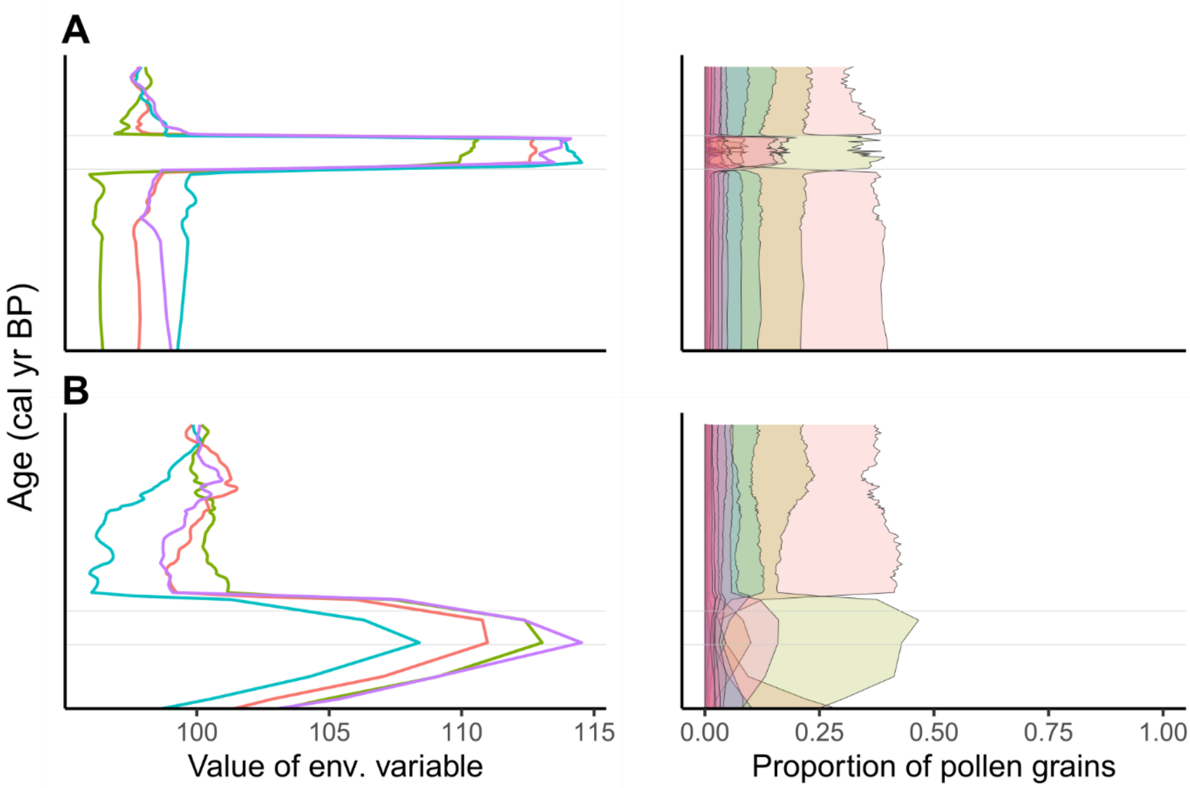

Figure S1. Example of the manipulation of environmental variables and simulated pollen taxa in a *recent* (A; 2000–3000 cal yr BP) and *late* (B; 5500–6500 cal yr BP) time period, i.e. 'focal area'. Note that the *late focal area* has a low density of levels and the *recent* focal area has a high density of levels.

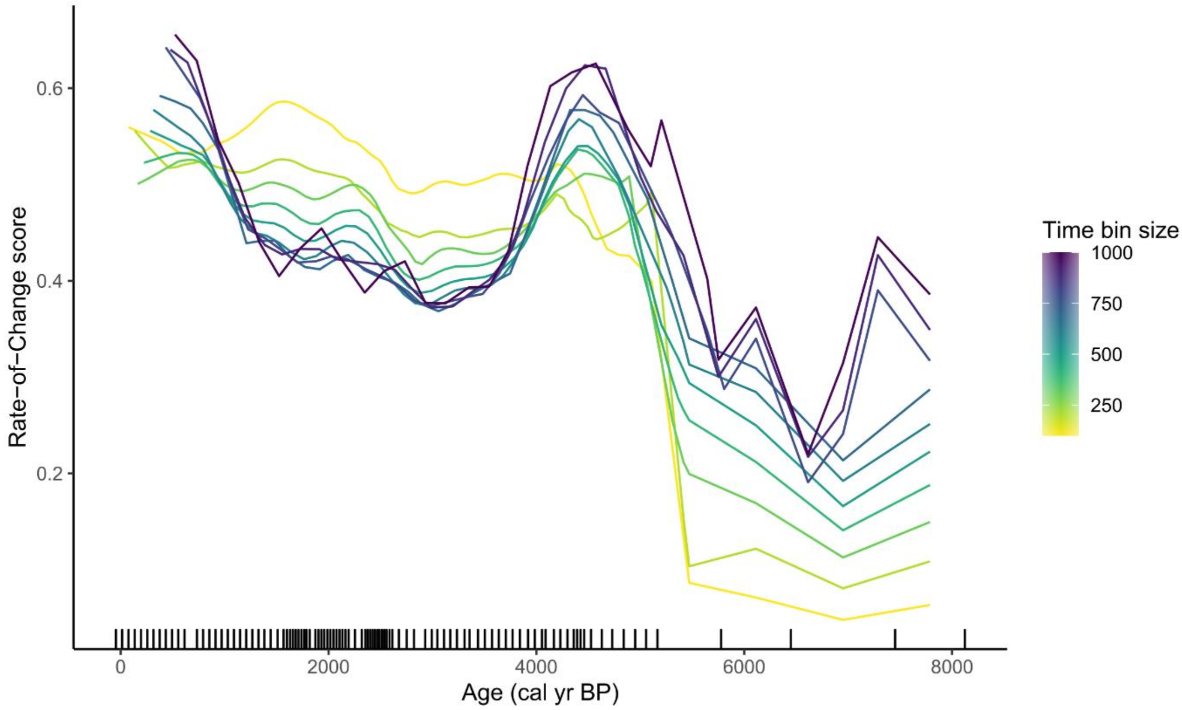

Figure S2. Rate-of-change score in Sequence A (Glendalough) calculated with various size of time bins using binning with moving window method. Age-weighted average and Chi-squared coefficient were selected for smoothing and dissimilarity. Black ticks at the y-axis indicates the position of stratigraphical levels.

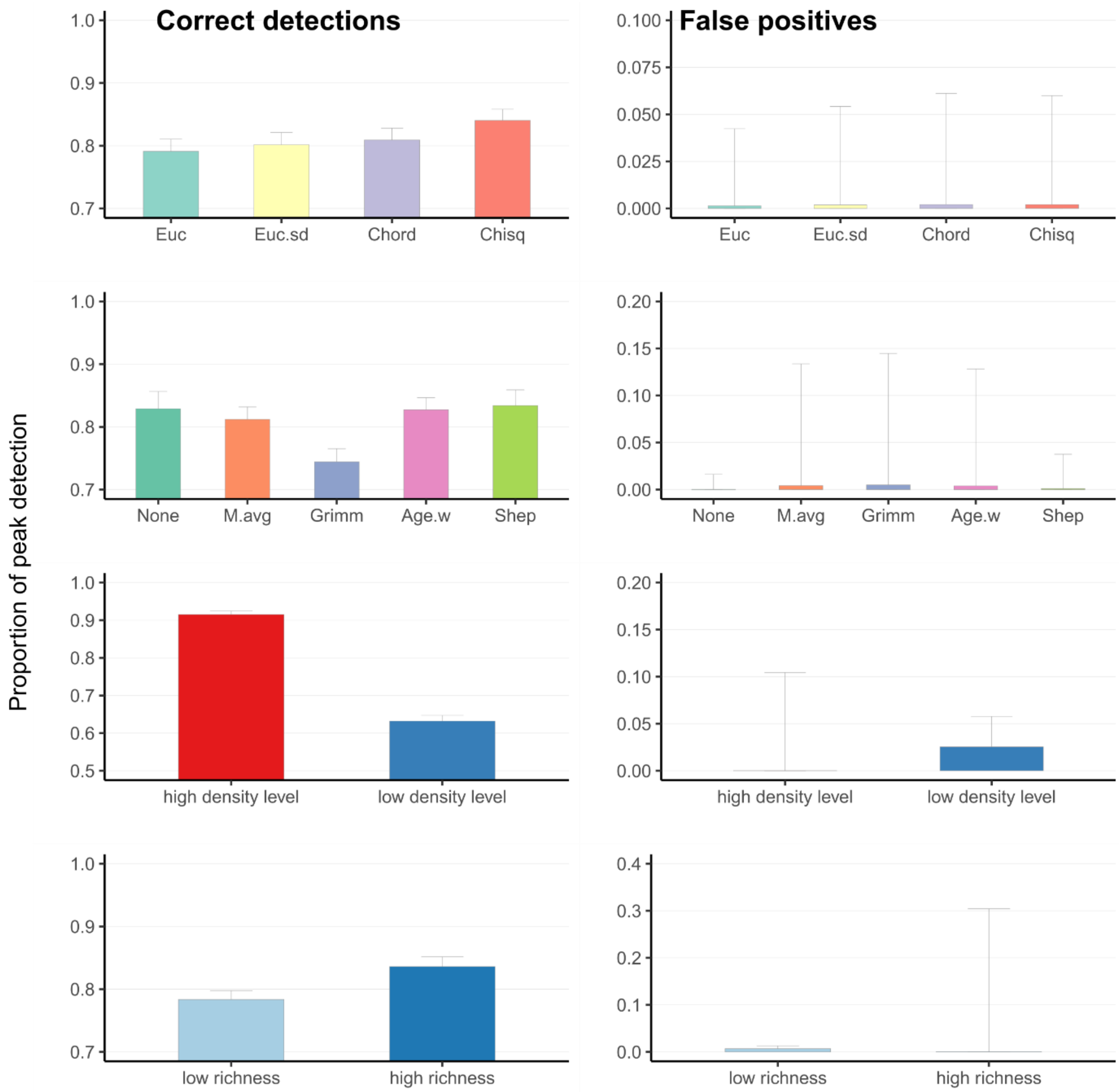

Figure S3. Comparison of estimated marginal means and 95% quantile of peak-point detection in the simulated datasets. Dissimilarity coefficient: Euc = Euclidian distance, Euc.sd = Standardised Euclidean distance, Chord = Chord distance, Chisq = Chi-squared coefficient. Smoothing of pollen data: None = data without smoothing, M.avg = moving average, Grimm = Grimm's smoothing, Age.w = age-weighted average, Shep = Shepard's 5-term filter.

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