

Pollen season of European beech (*Fagus sylvatica* L.) and temperature trends at two German monitoring sites over a more than 30-year period

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Abstract Although beech (*Fagus*) pollen are often disregarded, they play an allergological role. This study focused on pollen season (PS) of European beech (*Fagus sylvatica* L.) and mean yearly temperatures (T) at two climatically different sites (lowlands vs. Alps) in Germany. Pollen sampling was conducted with 7-day recording volumetric spore traps between 1982 and 2014. Both PS parameters (start, peak, length, annual pollen index [PI]) and T were compared in two periods (1982–1991 and 1992–2014), and

correlations between PS and T were analysed. At both sites, average PS occurred earlier in the second period. Statistically significant differences were proved at the alpine site in terms of start and peak of the season, and PI. On average, PS in the lowlands was shorter and occurred earlier than in the Alps. As is the case with a lot of temperate tree species, beeches show the masting phenomenon and PI differed greatly among the years. Mast years were much less frequent than non-mast years, and the differences between the pollen sums were significant. Average pollen counts at the alpine site were about three times higher than in the lowlands. At both sites, higher T was significantly correlated with an earlier start and peak of the season, and an increased PI. Trends of T over the years were significantly positive. Temperature increase as a part of climate change may contribute to an earlier occurrence of the flowering season of European beech and to higher airborne pollen concentrations.

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1 Introduction

Allergies are the most frequent chronic disease in all countries of the European Union. In a recent investigation, the prevalence of respiratory allergies had

already risen to 31 % in all age groups, but especially high prevalences are found in the younger age groups peaking at 20–40 years of age with the prevalence of more than 40 % (Blomme et al. 2013). Apart from the increase in numbers, physicians also note an increase in those patients who represent with uncontrolled severe chronic upper airway diseases (SCUAD) (Bousquet et al. 2009). On the other hand, allergies are still often perceived as being trivial in the medical professional world. In fact, half of the patients report that they have self-diagnosed their allergic rhinitis (Maurer and Zuberbier 2007). In consequence, under-treatment has become a big socio-economic problem causing mostly avoidable potential costs in the European Union alone between Euro 55 and 151 billion per annum (Zuberbier et al. 2014). In this context, it has become an increasing problem that even those patients visiting a doctor are often only tested for standard allergens mostly including the pollen of birch (*Betula*), grasses (*Poaceae*) and mugwort (*Artemisia*). But other trees pollinating in spring are often disregarded. In this context, a special emphasis may be put on beech (*Fagus*). This pollen is relevant in pathogenesis of springtime hay fever (Eriksson 1978; Wiebicke et al. 1987). There is evidence that beech pollen show cross-reactions with other pollen (e.g. oak [*Quercus*]) of the same botanical family (*Fagaceae*) or even of other families (*Betulaceae*, e.g. hazel [*Corylus*]) belonging to the same order (*Fagales*) (Eriksson et al. 1987; Egger et al. 2008; Hauser et al. 2011).

The ongoing climate change might also affect respiratory allergic diseases as it promotes an increased length and severity of pollen season (D'Amato et al. 2014). Due to the mainly man-made increase in greenhouse gas emissions, global temperature has distinctly increased over the past decades (D'Amato et al. 2014). Climate projections for Central Europe expect within the next decades a proceeding temperature increase, changed precipitation patterns and more frequent extreme events, such as heat waves, droughts, floods and thunderstorms (European Environmental Agency (EEA) 2012; D'Amato et al. 2014; Kovats et al. 2014). European beech (*Fagus sylvatica* L.) has to meet a challenge that is associated with its sensitivity to intensive droughts and water shortage during growing season, to milder winters, which could reduce the required winter chilling period and, on the other hand, to waterlogged soils and hindered nutrient uptake resulting from increased precipitation (Heide

1993; Sykes et al. 1996; Gessler et al. 2007; Körner and Basler 2010).

Annual pollen sums of European beech differ greatly among the years. This phenomenon that is called masting is also shown by a lot of other temperate tree species, e.g. birch (Jäger et al. 1991; Dahl and Strandhede 1996). During mast years, intensive flowering and fruiting of trees of the same species occur synchronously over large areas (Satake and Iwasa 2000; Dahl et al. 2013). Masting in European beech is controlled by endogenous and several exogenous factors (Piovesan and Adams 2001). The differences in annual pollen sums also have a clinical impact and should be considered by practicing physicians.

In this study, pollen season of European beech was investigated at two climatically different monitoring sites in Germany over a period of more than 30 years. The data go into the question of a possible shifting of beech pollen season and annual pollen sums associated with rising temperatures.

2 Materials and methods

2.1 Pollen measurements

2.1.1 Sampling

Pollen sampling was conducted at two German monitoring sites between 1982 and 2014. Seven-day recording volumetric spore traps (Hirst 1952) with Vaseline[®] as adhesive were installed in the north-west (Delmenhorst [53°3'N, 8°38'E]) and in the south (Oberjoch [47°31'N, 10°24'E]) of Germany and had a distance of about 620 km (Fig. 1). Delmenhorst (10 m above sea level [a.s.l.]) lies in the lowlands, about 70 km to the south of the North Sea coast, in north-western Germany. The trap was sited on the flat roof of a school building in the city centre and had a measuring height of about 17.5 m above street level (measuring period: 1982–1991 and 1993–2014). European beeches are widely spread in and outside the city. At a distance of about 10 km to the west of Delmenhorst, there is a great forest, where beeches account for 27 % (166.7 ha) (1999) of the trees. Oberjoch (1150 m a.s.l.) lies at the foot of a hillslope in the Bavarian Alps in Southern Germany. The trap was located on the terrace of a hospital at a height of



Fig. 1 Map of Germany with the two monitoring sites Delmenhorst (10 m a.s.l.) and Oberjoch (1150 m a.s.l.)

about 4.5 m above street level (period: 1982–1989 and 2004–2014) and on the balcony of a nearby hotel at a height of about 6 m above street level (period: 1995–2003). These two sampling locations were approximately 275 m away from each other. The surroundings are characterized by hillslopes with grazing land and forests, dominated by spruces (*Picea*), and a small forest of European beeches, spruces and maples (*Acer*) less than 100 m off the trap.

The climate in Delmenhorst is temperate. In Bremen (about 11.5 km to the east of Delmenhorst), the German Weather Service (DWD) measured a long-term (1981–2010) mean yearly temperature of 9.4 °C; mean yearly accumulated precipitation came to 696 mm and mean yearly sunshine duration amounted to 1545 h. The climate in Oberjoch is also temperate, but colder. In Oberstdorf (about 15 km to the south-west of Oberjoch), the DWD measured a mean yearly temperature of 6.6 °C, an accumulated precipitation of 1742 mm and a sunshine duration of 1605 h. In Oberjoch, winters are long and cold, so that mean yearly temperatures are lower than in

Delmenhorst, where winters are comparatively short and sometimes snowless.

2.1.2 Analysis

Light microscopic analysis of all daily samples, as recommended by Hecht (1994) and Jäger et al. (1995), was carried out by the same person. In each sample, *Fagus* pollen were counted in two horizontal central rows, which had together a total width of 970 µm, with a magnification of 250 diameters (oil immersion; numerical aperture: 0.75). The analysis led to daily means of pollen grains per cubic metre of air. In each year, the annual pollen index (PI), that is, the sum of all daily means of the year, was calculated. Years with a PI greater than or equal to the particular double long-term average in Delmenhorst and Oberjoch were defined as mast years. Pollen season (PS) was defined to cover 98 % of the PI (Galán et al. 1995); the first day of the season was the day with a cumulative total of ≥ 1 %, the last day the one with ≥ 99 %.

2.2 Temperature data

Air temperature measurements, conducted and provided by the DWD, were carried out in Bremen (near Delmenhorst) and Oberstdorf (near Oberjoch) at a height of 2 m above ground level between 1982 and 2014. Temperature data were used in the form of yearly means.

2.3 Statistical analysis

(1) In two periods (1982–1991 [first period] and 1992–2014 [second period]), both PS and mean yearly temperatures were compared with each other. Pollen measurements in Delmenhorst were taken from 1982 to 2014, with the exception of 1992, and in Oberjoch from 1982 to 1989 and from 1995 to 2014. It has to be considered that, compared to Delmenhorst, the difference between the averaged periods in Oberjoch is greater due to the missing data at the beginning of the second period. Temperature data were available from 1982 to 2014. Statistical significance was tested by Student's *t* test and confirmed by bootstrapping method. (2) For both monitoring sites, intercorrelation functions (CCF) were calculated between PS parameters (start, peak, length, and PI) and mean yearly

temperatures (confidence interval: 95 %). Concerning “start” and “peak”, days were counted from January 1 to the start date (day with a cumulative total of ≥ 1 % of the PI) and peak date (day with maximum daily pollen mean) of the particular year; low counts represent an early start and peak of the season, respectively. (3) For both sites, the PI of mast years and non-mast years were tested for significant differences by Student’s *t* test. (4) For both sites, the trend of mean yearly temperature was investigated over the years by linear regression analysis. (5) Spearman’s correlation coefficient was calculated in order to compare PS intensity (in the form of the PI) at both locations. All analyses were carried out using SPSS 22.

3 Results

3.1 *Fagus* pollen season

3.1.1 Start, peak, end and length of the season

For both monitoring sites, the dates of the average start, peak, end and length of the season, and the corresponding shifts between the two periods are summarized (Table 1). Comparing both periods, PS shifted forward at both sites. On average, season started 11 days (Delmenhorst) respectively 14 days (Oberjoch) earlier in the second period; the peak occurred 6 respectively 13 days earlier, and season ended 7 respectively 13 days earlier. The average length of the season increased by 4 days respectively 1 day. In Delmenhorst, significant differences between the periods proved in terms of “peak” ($p = 0.040$) and “length” ($p = 0.040$) by Student’s *t* test could not be verified by bootstrapping method ($p = 0.070$ respectively $p = 0.052$). In Oberjoch, significant differences were proved regarding “start” (Student’s *t* test: $p = 0.046$; bootstrapping method: $p = 0.020$) and “peak” (Student’s *t* test: $p = 0.018$; bootstrapping method: $p = 0.007$). Comparing both sites, measurements in Delmenhorst revealed, on average, an earlier start, peak and end, and a shorter season duration than in Oberjoch.

3.1.2 Pollen index

At both sites, PI often differed greatly from year to year (Figs. 2, 3). Years with high PI were separated by up to three years with low sums below the particular

long-term average (Delmenhorst: PI = 277; Oberjoch: PI = 882). In one case, low sums in Oberjoch lasted for 6 years (1984–1989); taking the average PI of the first period (PI = 377) as a basis for Oberjoch between 1984 and 1989, separation comprised only two years with low sums in each case (1984 and 1985; 1987 and 1988). Partly, a biannual rhythm, e.g. 2007–2012, was determined. Mast years, that is, years with PI ≥ 554 (Delmenhorst) and PI ≥ 1764 (Oberjoch), respectively, mostly went along with low sums in the previous and the following year. The difference between the PI of mast years and non-mast years is significant for both sites (Student’s *t* test: $p < 0.001$). Mast years (Delmenhorst: 6; Oberjoch: 6) occurred less frequently than non-mast years (Delmenhorst: 26; Oberjoch: 21). The highest PI in Delmenhorst was reached in 2000 (PI = 1276), in Oberjoch in 2014 (PI = 3972). On average, pollen counts in Oberjoch were about three times higher than in Delmenhorst. The average PI in the first period was only 51 % (Delmenhorst) respectively 35 % (Oberjoch) of the average PI in the second period. In Oberjoch, the difference is significant (Table 1). PS intensity showed a significantly positive correlation between both locations ($r = 0.538$, $p = 0.004$).

3.1.3 Pollen season and temperature

For both sites, intercorrelation calculations (Table 2) revealed significantly negative correlations between mean yearly temperature and both start and peak of the season, that is, the higher the mean yearly temperature, the earlier both the PS started and the peak occurred. In terms of PI, significantly positive correlations could be proved for both sites, that is, the higher the mean yearly temperature, the higher the PI was. As to the length of the season, no significant correlations could be found.

3.2 Temperature

(1) Comparing both periods, mean yearly temperature in Bremen increased by 0.6 °C, that is, from 9.1 °C (maximum value [max]: 10.3 °C; minimum value [min]: 7.9 °C; standard deviation [SD]: 0.86) in the first to 9.7 °C (max: 11.1 °C; min: 7.7 °C; SD: 0.72) in the second period. This increase is significant (Student’s *t* test: $p = 0.023$; bootstrapping method: $p = 0.024$). Mean yearly temperature in Oberstdorf

Table 1 Average start, peak, end and length of *Fagus* pollen season and pollen index, and the corresponding shifts respectively differences between the first (1982–1991) and second (1992–2014) period at two monitoring sites (Delmenhorst in north-western Germany and Oberjoch in Southern Germany)

<i>Fagus</i>		Delmenhorst		Oberjoch		
		1st period	2nd period	1st period	2nd period	
Pollen season	Start	Date	18 April	7 April	26 April	12 April
		Shift		11 days earlier		14 days earlier
		Sig.				$p = 0.046$ (<i>t</i> test) $p = 0.020$ (b. m.)
		Min	11 April	4 April	23 April	3 April
		Max	4 May	6 May	16 May	20 May
			Compared to Oberjoch			
			8 days earlier	5 days earlier		
	Peak	Date	2 May	26 April	21 May	8 May
		Shift		6 days earlier		13 days earlier
		Sig.		$p = 0.040$ (<i>t</i> test)		$p = 0.018$ (<i>t</i> test) $p = 0.007$ (b. m.)
		Min	21 April	17 April	6 May	4 April
		Max	16 May	12 May	3 June	6 June
			Compared to Oberjoch			
			19 days earlier	12 days earlier		
	End	Date	21 May	14 May	10 June	28 May
Shift			7 days earlier		13 days earlier	
Min		21 April	30 April	27 May	17 April	
Max		14 June	24 May	17 June	15 June	
		Compared to Oberjoch				
		20 days earlier	14 days earlier			
Length		34 days	38 days	46 days	47 days	
	Shift		4 days longer		1 day longer	
	Sig.		$p = 0.040$ (<i>t</i> test)			
	Min	1	1	21	10	
	Max	42	34	46	45	
	SD	12.25	9.08	9.30	12.04	
		Compared to Oberjoch				
		12 days shorter	9 days shorter			
Pollen index		168	327	377	1084	
	Diff.		159 more		707 more	
	Sig.				$p = 0.026$ (<i>t</i> test) $p = 0.039$ (b. m.)	
	Min	1	1	52	0	
	Max	554	1276	1050	3972	
	SD	187.72	400.76	327.86	1291.04	
		Compared to Oberjoch				
		209 less	757 less			

Measuring period: 1982–2014 (Delmenhorst: without 1992; Oberjoch: without 1990–1994); Sig. = significant difference proved by Student's *t* test (*t* test) and bootstrapping method (b. m.); Min = earliest date (start, peak, end), shortest duration (length) resp. lowest count (pollen index); Max = latest date, longest duration resp. highest count; SD = standard deviation; Diff. = difference

increased by 0.4 °C (from 6.5 °C [first period; max: 7.1 °C; min: 5.9 °C; SD: 0.50] to 6.9 °C [second period; max: 8.2 °C; min: 5.4 °C; SD: 0.64]), but a

significant difference could not be proved (Student's *t* test: $p = 0.093$; bootstrapping method: $p = 0.084$). (2) Linear regression analysis revealed a significantly

Fig. 2 *Fagus* pollen index at Delmenhorst from 1982 to 2014 (without 1992). Pollen indexes in *bold* indicate mast years ($PI \geq 554$)

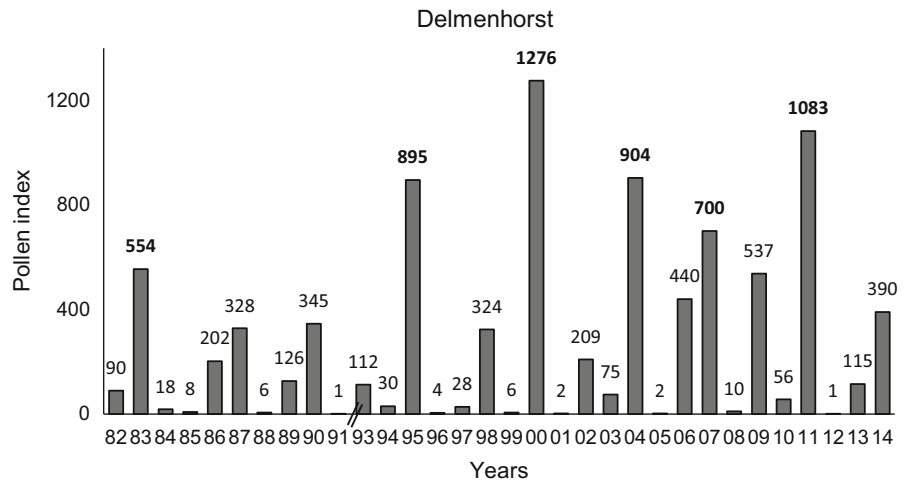


Fig. 3 *Fagus* pollen index at Oberjoch from 1982 to 2014 (without 1990–1994). Pollen indexes in *bold* indicate mast years ($PI \geq 1764$)

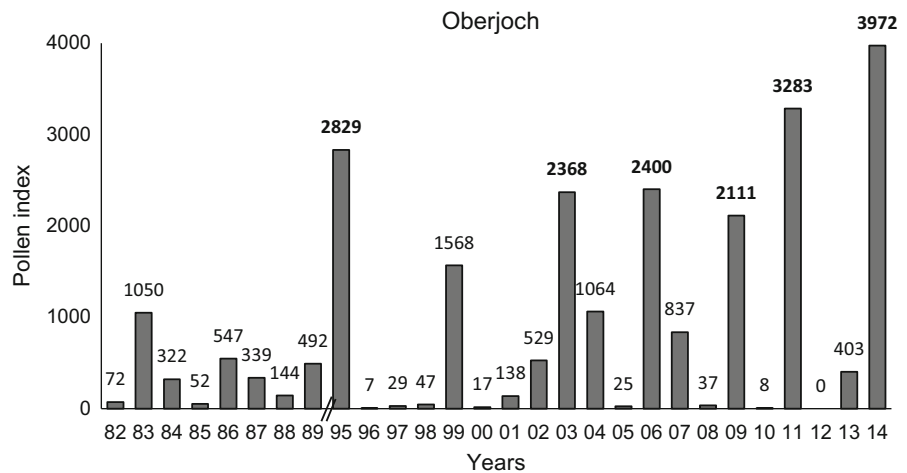


Table 2 Intercorrelation coefficients (CCF [intercorrelation function], “lag 0” [no shifting of the time series]) between *Fagus* pollen season in Delmenhorst respectively Oberjoch and mean yearly temperatures in Bremen (near Delmenhorst) respectively Oberstdorf (near Oberjoch) between 1982 and 2014

	Start	Peak	Length	Pollen index
Delmenhorst	-0.516	-0.563	(0.070)	0.387
Oberjoch	-0.611	-0.537	(0.026)	0.488

Coefficients in brackets not significant

positive trend of mean yearly temperature in Bremen from 1982 to 2014. On average, temperature increased by 0.037 °C per annum ($p = 0.007$). In Oberstdorf, average temperature increase was 0.023 °C per annum ($p = 0.033$). This trend could be proved being significant as well.

4 Discussion

In this study, PS of *Fagus sylvatica* and mean yearly temperature trends were analysed at two climatically different monitoring sites in Germany between 1982 and 2014. A comparison of two periods (1982–1991 and 1992–2014) at both the lowland site in Delmenhorst and the alpine site in Oberjoch revealed, on average, an earlier occurrence of the season in the second period. However, statistically significant differences could only be proved in terms of the start and peak in Oberjoch. Due to the comparatively warm climate in Delmenhorst, average start, peak and end of the season occurred earlier than in Oberjoch. The onset differed to a less extent possibly because of long-distance transport at the alpine site, due to active

exchange of air masses, before local trees started to flower, and thus, season in OJ was longer. At both sites, the average length of the season between the periods changed by a few days only, so that allergic persons suffering from pollinosis caused by beech pollen allergens are mainly faced with an earlier, but not distinctly prolonged season. In addition, average PI was higher in the second period, which was proved to be significant in Oberjoch as well. Average pollen counts in Oberjoch were about three times higher than in Delmenhorst, possibly due to the neighbouring group of European beeches. Annual sums at both sites varied among the years, that is, years with high or very high pollen sums were separated by up to 3 years with low sums, sometimes in the form of a biannual rhythm. Beeches and a lot of other temperate tree species, e.g. birch (Jäger et al. 1991; Dahl and Strandhede 1996), show this phenomenon that is called masting. Despite the great distance, PS intensity showed a significantly positive correlation between both locations. Synchronized inter-annual fluctuations of flowering intensity can cover large geographical areas, and they can even occur among different tree genera, e.g. *Betula*, *Alnus* (alder) and *Corylus*, resulting in high concentrations of many different allergenic pollen in the same year (Ranta and Satri 2007). Kasprzyk et al. (2014) determined a 3-year cycle of mast years of European beech. A certain periodicity is characteristic, and it has been shown that the interval between two strong masting events has decreased in the past decades (Hilton and Packham 2003; Schmidt 2006; Övergaard et al. 2007). However, masting in two consecutive years occurs rarely, possibly caused by a depletion of stored nutrient resources inside the tree after a strong masting event (Övergaard et al. 2007). In Delmenhorst and Oberjoch, no regularity could be found out. It could only be ascertained that mast years occurred less frequently than non-mast years, and the differences in the particular PI were significant. Masting in European beech is controlled by endogenous and exogenous factors. A moist and cool summer 2 years before masting and a drought in the early summer in the previous year, that is, during the floral formation process, seem to be key environmental triggers (Piovesan and Adams 2001). Beeches may use the moist-cool summer to build up carbohydrate resources which are used, triggered by a drought in the following year, for the formation of flower buds (Piovesan and Adams 2001). Temperatures both from July to

September of the previous year, and before and at the beginning of the season are an important factor for beech pollen counts as well (Kasprzyk et al. 2014). As a late-successional species, beeches are also controlled by photoperiod, that is, day length relative to night length (Körner and Basler 2010). The weather conditions within a mast year, especially during the flowering period, are also relevant as they influence pollen release and distribution (Koenig and Ashley 2003). High annual pollen sums can result from favourable weather conditions and a synchronously high pollen emission by the majority of the trees of a large area, indicated by a short peak time (Dahl et al. 2013). A weather-related restriction of pollen dispersal could cause a reproductive failure in wind-pollinated species (Koenig and Ashley 2003). The amount of pollen produced in mast years increases the probability of a successful pollination (Nilsson and Wästljung 1987).

As is the case with most temperate tree species, start of beech flowering period is governed by temperature in the form of accumulated heat units above a threshold level in the months before (Dahl et al. 2013). In Delmenhorst and Oberjoch, higher mean yearly temperatures were significantly correlated with an earlier start and peak of the season, and an increased PI. In addition, the trends of mean yearly temperatures over the years were significantly positive in the nearby towns Bremen and Oberstdorf. Therefore, temperature increase as a part of climate change may contribute to an earlier occurrence of the PS of European beech and to higher pollen concentrations. However, increasing pollen counts could also result from the man-made increase in atmospheric carbon dioxide (CO₂) (Ziello et al. 2012). Forest area of *Fagus sylvatica* in Germany has also increased, as shown by two studies for an observation period between 1987 and 2012 (Polley and Kroihner 2006; <https://bwi.info>), so that there might be an increased number of nubile trees due to planting some decades ago or less felling. As mentioned by Kasprzyk et al. (2014) referring to a study from Suszka in 1990, single European beech can become nubile at the age of 20 years, but in dense stands, trees start to flower and to fruit at the age of 60–70 years.

The findings clearly have a clinical impact for allergy sufferers. (1) Patients are often only diagnosed with a limited number of pollen allergens, trusting on possible cross-reactivity of allergens, but this

economical trend bears the danger that individually important allergy sources are overlooked. (2) Patient history is important in correlating symptoms and sensitization patterns to decide which allergens are relevant. However, with beech there is a high difference in pollen load during the different years, which the practicing doctor, just looking at the pollen calendar, would not necessarily know. Again, this may lead to under-diagnoses of beech related allergic respiratory diseases.

5 Conclusions

Pollen season of European beech seems to be affected by rising temperatures as a part of climate change. Allergy sufferers might be faced with an earlier occurrence of the season and higher annual pollen sums. Beeches near to the investigated sites need recovery times indicated by up to 3 years of low pollen sums to prepare for a year of intensive flowering.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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