Int J Biometeorol (2001) 45:64–74

ORIGINAL ARTICLE

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Correlation of spring spore concentrations and meteorological conditions in Tulsa, Oklahoma

Received: 5 July 2000 / Revised: 20 December 2000 / Accepted: 22 December 2000

Abstract Different spore types are abundant in the atmosphere depending on the weather conditions. Ascospores generally follow precipitation, while spore types such as *Alternaria* and *Cladosporium* are abundant in dry conditions. This project attempted to correlate fungal spore concentrations with meteorological data from Tulsa, Oklahoma during May 1998 and May 1999. Air samples were collected and analyzed by the 12-traverse method. The spore types included were *Cladosporium, Alternaria, Epicoccum*, *Curvularia*, *Pithomyces*, *Drechslera*, smut spores, ascospores, basidiospores, and other spores. Weather variables included precipitation levels, temperature, dew point, air pressure, wind speed, wind direction and wind gusts. There were over 242.57 mm of rainfall in May 1999 and only 64.01 mm in May 1998. The most abundant spore types during May 1998 and May 1999 were *Cladosporium*, ascospores, and basidiospores. Results showed that there were significant differences in the dry-air spora between May 1998 and May 1999. There were twice as many *Cladosporium* in May 1998 as in May 1999; both ascospores and basidiospores showed little change. Multiple regression analysis was used to determine which meteorological variables influenced spore concentrations. Results showed that there was no single model for all spore types. Different combinations of factors were predictors of concentration for the various fungi examined; however, temperature and dew point seemed to be the most important meteorological factors.

Keywords Aerobiology · *Cladosporium* · Basidiospores · Ascospores · Multiple regression

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Introduction

Fungal spores are an ever-present component of the atmosphere with concentrations known to fluctuate according to meteorological conditions. The distinction between dry-air spora and wet-weather air spora is well known. The dry-air spora includes *Cladosporium*, *Alternaria*, *Epicoccum*, *Drechslera*, *Pithomyces*, and *Curvularia*, and smut spores (Katial et al. 1997; Hjelmroos 1993; Timmer et al. 1998). Although many other spore types are included in the dry-air spora, these are the most prominent in the Tulsa area and are also well-known allergens (Levetin 1995). Members of the dry-air spora are found in the greatest abundance in the atmosphere with conditions of low humidity and high wind speeds, generally during the warmer afternoon hours (Levetin 1995). Ascospores and basidiospores dominate the wet-air spora in Tulsa. Ascospore concentrations will increase during and after rainstorms (Bush 1989), whereas basidiospores have a more predictable diurnal pattern, with an early-morning peak and late–afternoon depression corresponding to the diurnal rhythm of relative humidity (Li and Kendrick 1994; Hasnain 1993; Tarlo et al. 1979). The wet-air spora requires moisture for release, and thus increases in number after precipitation events, but excessive rain tends to wash the spores out of the atmosphere (Burge 1986; Horner et al. 1992).

Although ascospore concentrations are related to rainfall, their responses to different meteorological conditions are difficult to characterize. Studies of *Didymella* have shown that rain is not essential for peak spore levels (Richardson 1996). Richardson found peaks on days when there had been no rain in the days before, but he also saw peaks during and up to 1 h following rainfall. When the humidity at night was appropriately high, actual rain was not necessary for high concentrations of spores to be recorded. Gadoury et al. (1998) found that between 91% and 100% of *Venturia* ascospores released during rain were only captured during daylight between 0700 and 1800 hours. They also determined that rate of release was proportional to light intensity (Gadoury et al. 1998).

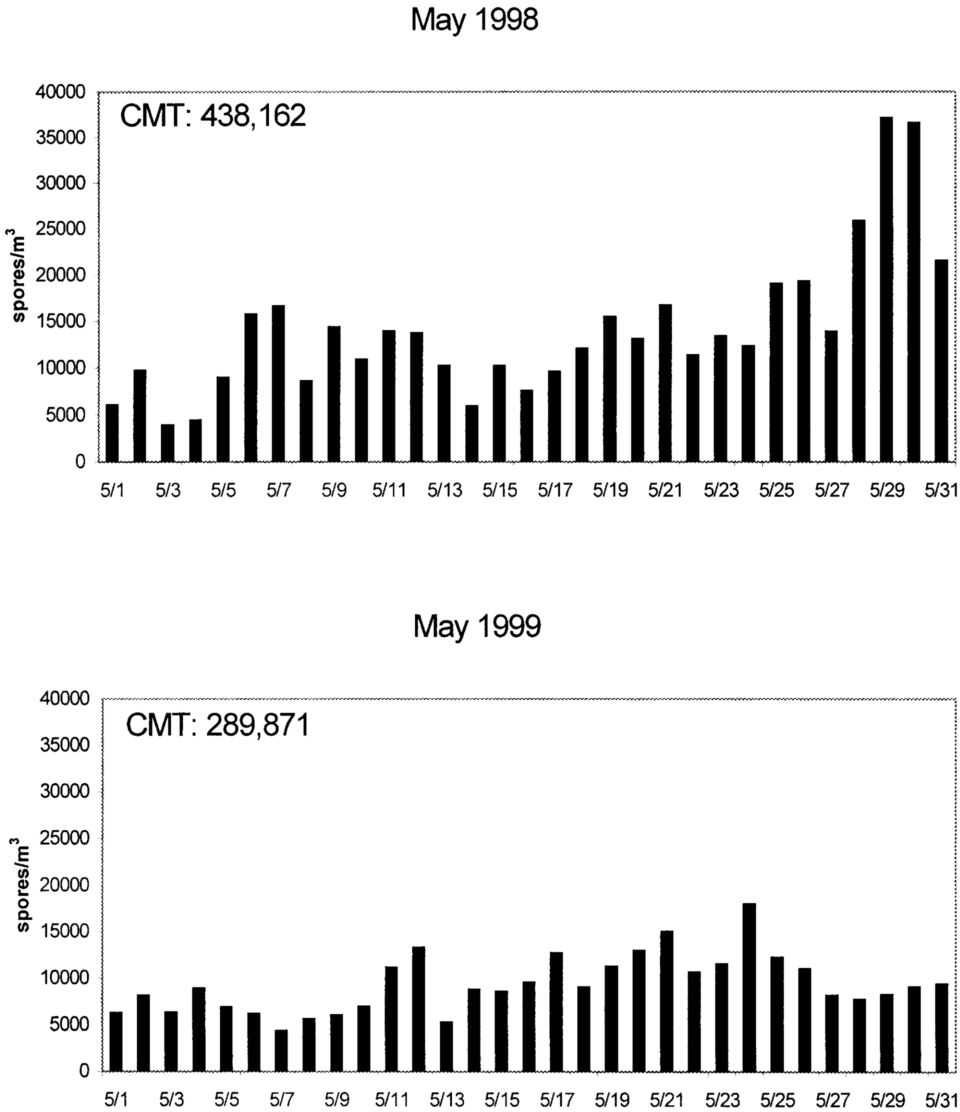
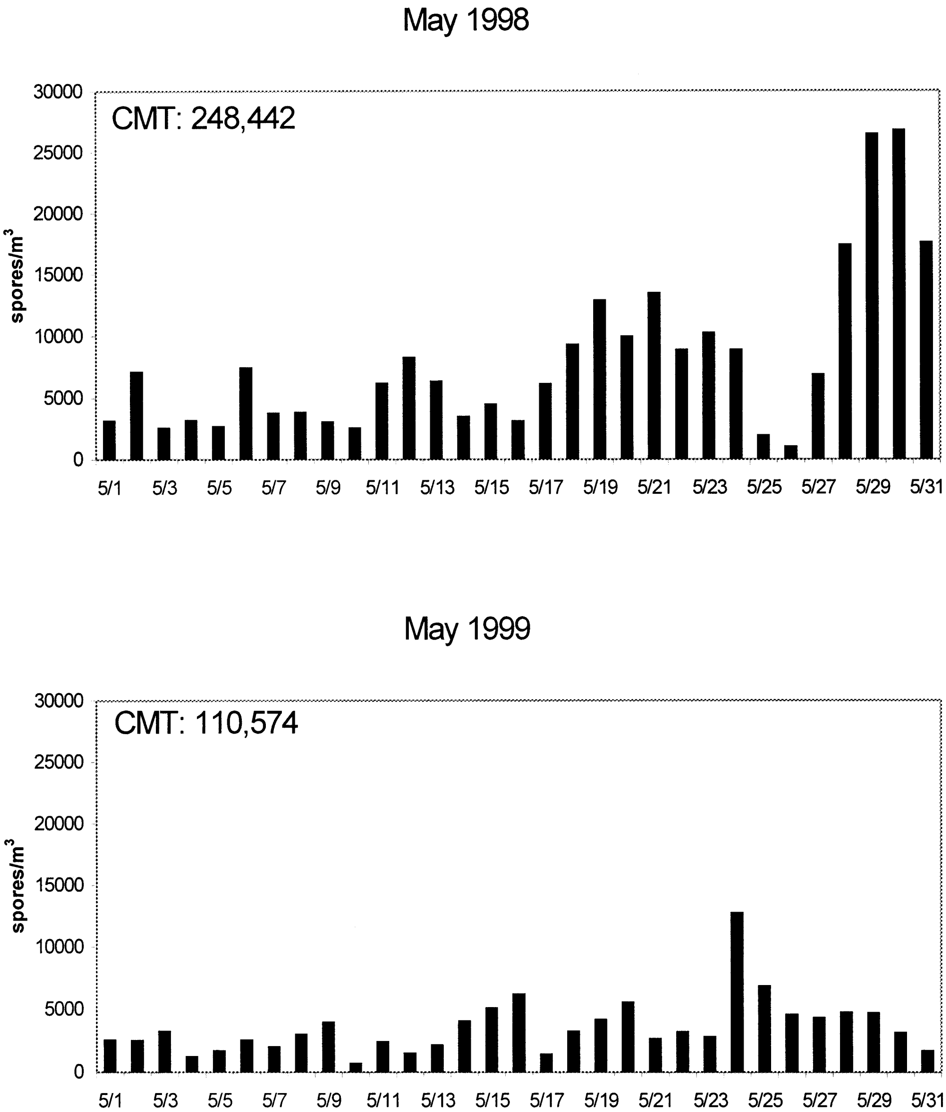


Fig. 1 Average daily concentration of total airborne spores in May 1998 and May 1999

Airborne allergens, including fungal spores, and climatic changes may influence the symptoms of asthma patients. Isolated cases suggest that meteorological events such as thunderstorms and dust storms have been correlated with increased asthma-related problems in the general population (Epton et al. 1997). For example, an epidemic in June 1994 occurred in London, during which the local hospitals saw a tenfold increase in hospital admissions for asthma during and immediately preceding a thunderstorm. This event has been well documented, and some theories hypothesize that an increase in ascospore and basidiospore concentrations contributed to the epidemic (Venables et al. 1997). Basidiospores, and, in particular *Ganoderma*, have been shown to elicit an allergic response in some patients (Cutten et al. 1988). In addition, *Didymella* ascospores are a known trigger to late summer asthma (Richardson 1996). If the relationship between meteorological conditions and fungal spore concentrations could be conclusively established, this could provide a huge benefit to patients with known allergies to fungal spores. Knowledge of this relationship would allow allergy patients to take preventative measures prior to predicted high concentrations of particular allergens, thereby reducing needless suffering.

This laboratory has previously shown that components of the dry-air spora, ascospores and basidiospores tend to increase in May in the Tulsa area and typically remain high all summer with yearly peaks generally in September (Levetin, 1991; Crotzer and Levetin 1996, Levetin et al. 1998). The effect of climate on spore concentrations in this area is less well known. In this study, we correlated fungal spore concentrations with meteorological data in Tulsa, Okla. from May 1998 and May 1999. These months were selected because they represented climatic extremes, May 1998 being an exceptionally dry month and May 1999 having unusually high precipitation levels. The specific aim of this study was to determine how the difference in rainfall between these two months affected the spore concentrations.

Fig. 2 Average daily concentration of *Cladosporium* conidia in May 1998 and May 1999 *CMT* cumulative monthly total



Materials and methods

Air sampling was conducted on the roof of Oliphant Hall at The University of Tulsa, approximately 12 m above ground. The University of Tulsa is located in a residential area about 5 km from the business center and 8 km from the geographical center of Tulsa. Tulsa is an urban area in northeast Oklahoma with a population of approximately 500,000 and a mild continental climate. Ecologically Tulsa is in a transition zone between deciduous forests and tall-grass prairie.

A Burkard volumetric spore trap was used for atmospheric sampling. Melinex tape, greased with a thin layer of Lubriseal, was mounted on the drum within the sampler. The drum, which rotates by the intake orifice at 2 mm/h, was changed weekly. The exposed tape was removed and cut in 48 mm segments, which represent 24-h periods. These segments were mounted on microscope slides and stained with basic fuchsin in a glycerin-jelly mounting medium. The slides were analyzed at 1000 X magnification using the 12-traverse method, where every other hour was read by examining a vertical traverse on the tape every 4 mm. Slides from 1 May to 31 May 1998 and 1 May to 31 May 1999 were analyzed. The spore categories counted included *Cladosporium, Alternaria, Epicoccum, Curvularia, Pithomyces, Drechslera*, smut spores, ascospores, basidiospores and other spores. "Other" spores included partial or unidentifiable spores, as well as known spores not included in the above categories. The spore counts were converted into atmospheric concentrations and expressed as spores per cubic meter of air. Daily averages were calculated from the hourly concentrations. For statistical analysis air sampling data were logarithmically transformed to normalize the data. A cumulative monthly total (CMT) was calculated for each spore type by summing all of the daily averages for the entire month.

Meteorological data were obtained from the National Oceanic and Atmospheric Administration weather station in Tulsa, which is located approximately 8 km northeast of the sampling site. The meteorological data included the hourly readings of temperature, dew point, wind speed, and atmospheric pressure. To arrive at daily readings, values were averaged over the 24-h period beginning at midnight. Precipitation values for hourly data were obtained by summing the previous 2 h, and daily values from the sum over the entire day. Two additional data categories used for the hourly analysis include wind direction and gustiness. The meteorological data were correlated with all spore types counted using Statistica 5.0 analytic software. Multiple regression analysis was performed using a forward stepwise mode.

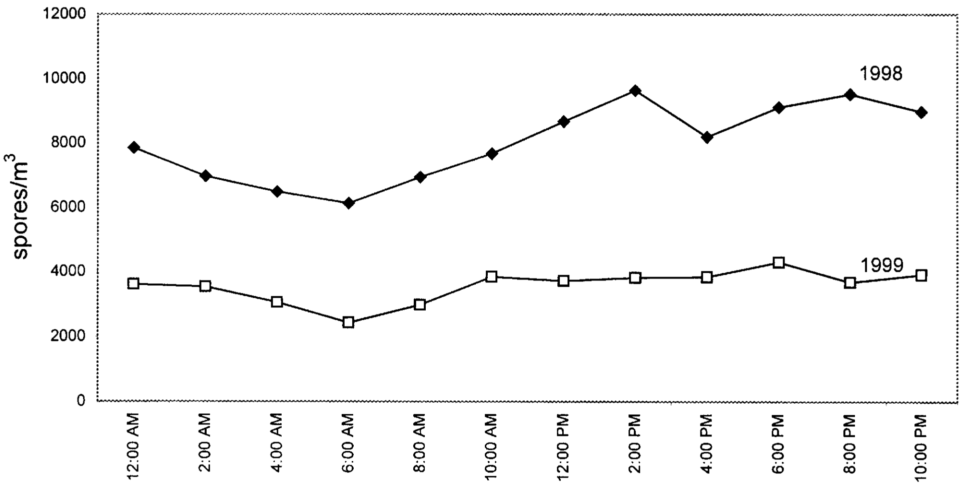


Fig. 3 *Cladosporium* diurnal rhythm for May 1998 and May 1999

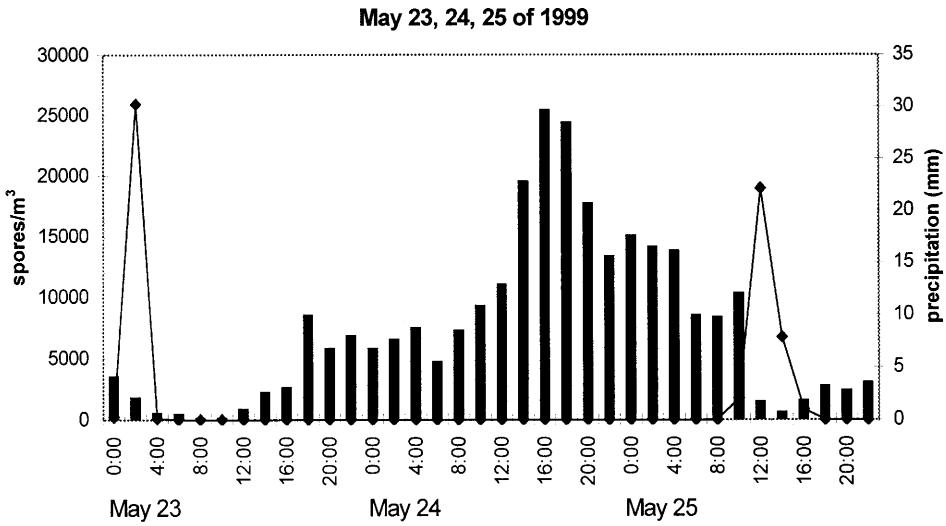


Fig. 4 Hourly airborne *Cladosporium* conidia and precipitation on 23, 24 and 25 May 1999

Table 1 Average meteorological conditions during May in Tulsa, Oklahoma

Parameter	1998	1999	30-year av.
Temperature (°C)	22.72	20.06	20.56
Precipitation (mm)	64.01	242.57	138.94
Number of days with rain	7	12	10.1
Dew point (°C)	16.39	13.89	14.39
Pressure (mm)	739.90	741.68	741.68
Wind speed (m/s)	3.98	4.02	4.78

Table 2 Average monthly concentration of dominant members of the air spora during May 1998 and May 1999

Spore type	1998	1999	t_{30}	*P*
Cladosporium	8,014	3,567	3.637	0.000512
Alternaria	272	116	2.784	0.004606
Epicoccum	40	14	3.570	0.000613
Curvularia	2	1	2.560	0.007875
Pithomyces	3	2	0.733	0.234628
Drechslera	21	13	2.275	0.015125
Smut spores	454	379	0.929	0.180100
Ascospores	3,849	3,783	0.063	0.475021
Basidiospores	1,307	1,223	0.679	0.251030
Other	173	252	–2.527	0.008497
Total	14,134	9,351	3.274	0.001336

Results

In this study, we chose to examine May 1998 and May 1999 primarily because of the difference in rainfall (Table 1). There were also small differences in temperature and dew point, but little difference in other meteorological parameters.

Comparisons of the air spora during these two months showed major differences in CMT, monthly average concentrations, peak concentrations, and shifts in the diurnal rhythm. Our results showed that there were significant differences in several members of the dry-air spora over the 2 months but little difference in ascospores and basidiospores (Table 2).

In May 1998 the CMT for total spores was 438,162 and in May 1999 289,871, approximately 34% lower (Fig. 1). In addition, the average monthly concentrations were significantly different (Table 2). 1998 had the

Fig. 5 Average daily concentration of *Cladosporium* conidia and temperature in May 1998

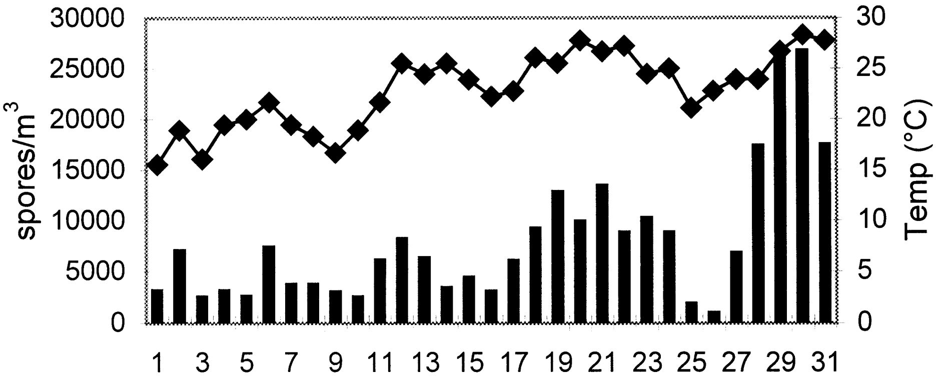
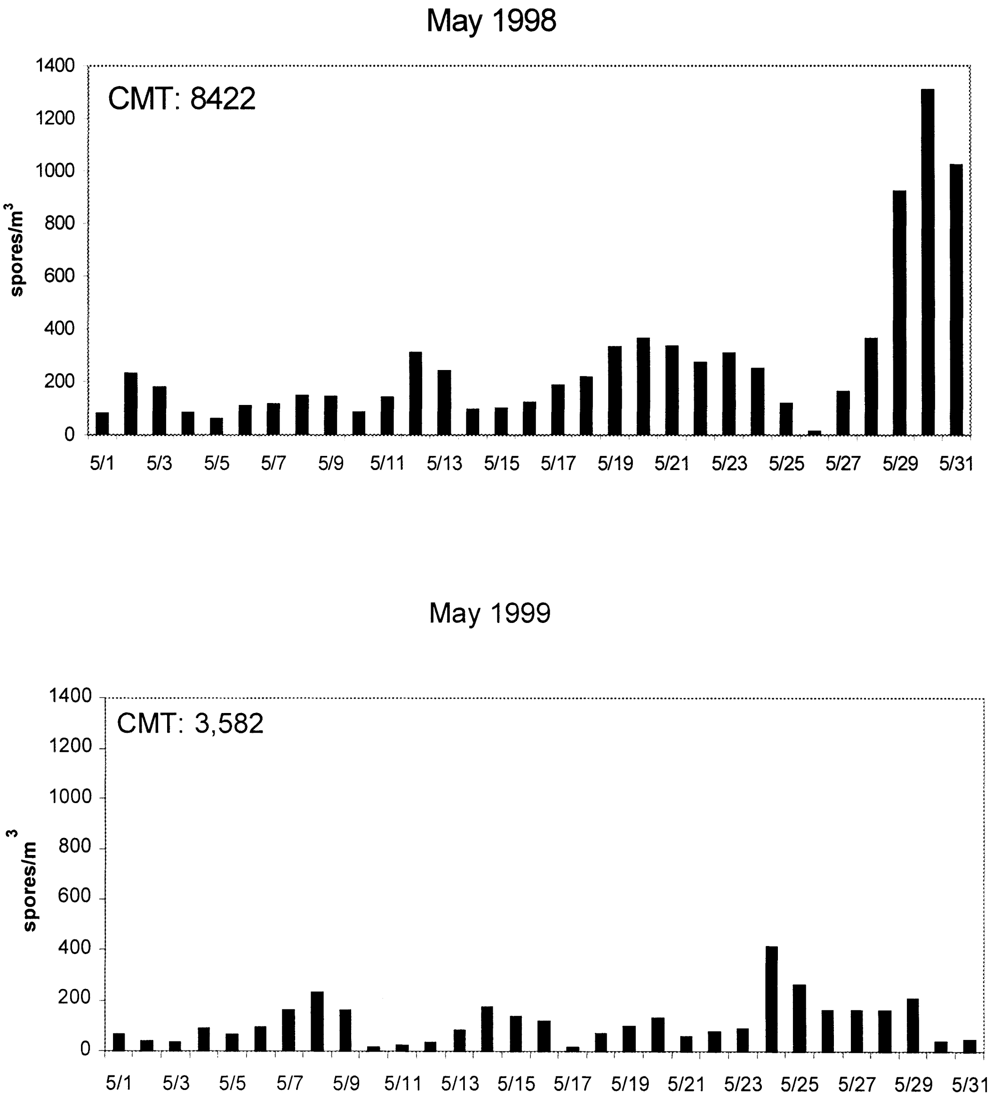


Fig. 6 Average daily concentration of *Alternaria* conidia in May 1998 and May 1999



monthly peaks on 29 May and 30 May, with concentrations over 35,000 spores/m^3. Average daily concentrations prior to 29 May ranged from about 8,000 to 18,000 spores/m^3. There were much lower concentrations in May 1999, with typical levels below 12,000 spores/m^3 and a peak on 24 May of about 18,000 spores/m^3.

The CMT for *Cladosporium* was 248,442 in 1998, and in 1999 it was less than half that level at 110,547 (Fig. 2). The average monthly concentrations were significantly different for the 2 years (Table 2). The diurnal distribution of airborne *Cladosporium* conidia differed during the 2 months (Fig. 3). In both years the lowest

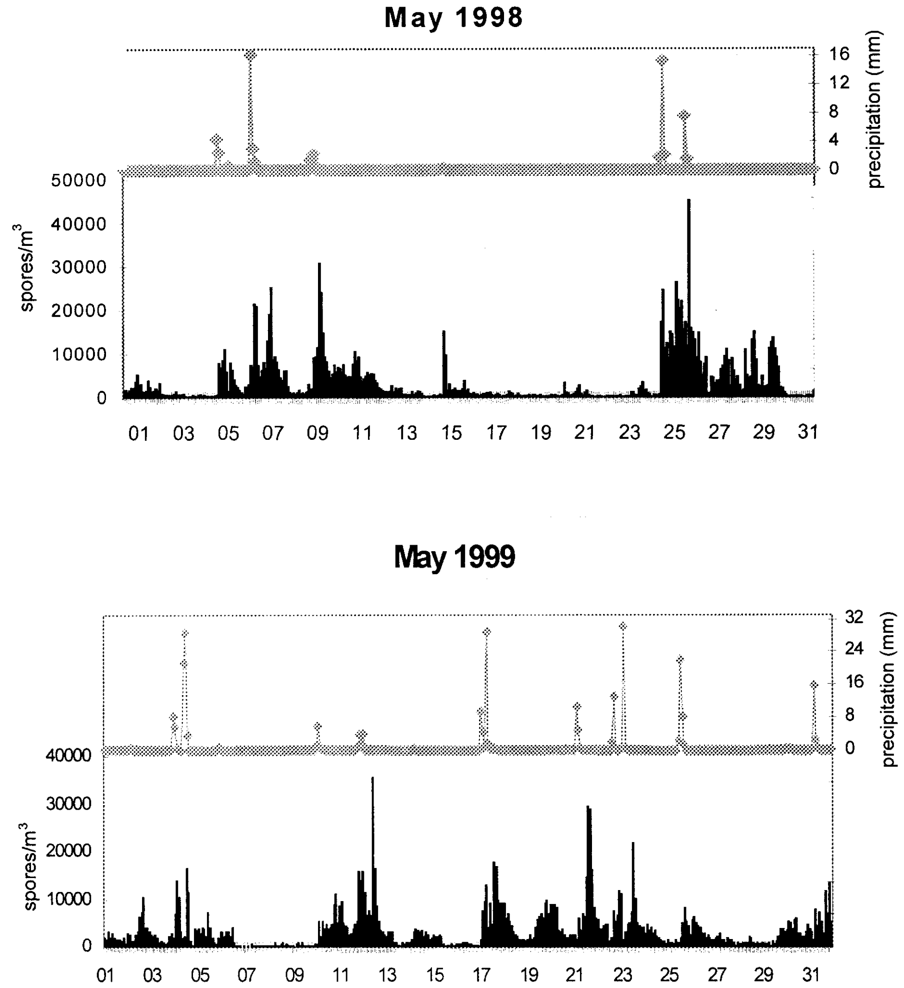


Fig. 7 Hourly airborne ascospores and precipitation in May 1998 and May 1999

concentration was found at 6 a.m. In May 1998, the peak was at 2 p.m. with a slight dip at 4 p.m. By contrast, in May 1999, the average concentrations during the hours between 10 a.m. and 10 p.m. formed a plateau.

The effect of rainfall on the *Cladosporium* concentrations can best be illustrated by 23, 24 and 25 May 1999 (Fig. 4). These days showed variation in *Cladosporium* concentrations in response to precipitation. There were about 3,000 spores/m^3 at midnight on the 23rd. Precipitation, which deposited approximately 30 mm of rain at 2:00 a.m., was followed by *Cladosporium* concentrations of almost zero. At noon on the 23rd, the *Cladosporium* concentrations began to rise, continuing until the 3-day peak at 4 p.m. on the 24th with over 25,000 spores/m^3. The concentrations slowly declined to about 10,000 spores/m^3 at 10 a.m. on the 25th, consistent with the diurnal rhythm seen in the 1998 data (Fig. 3).

Rain also fell at noon with about 23 mm precipitation, followed again by a rapid decline in *Cladosporium* concentrations. By about 4 p.m. *Cladosporium* values began increasing again.

A strong association also existed between average daily temperature and average daily *Cladosporium* concentrations in May 1998 (r=0.7; P<0.05). Although there were periods of decreasing temperature concurrent with declining *Cladosporium* concentrations, the overall trend showed that both mean daily temperature and *Cladosporium* concentrations rose as the month progressed (Fig. 5).

Very similar concentration patterns were seen for *Alternaria*. The CMT for *Alternaria* was 8,422 and 3,582 for May 1998 and May 1999 respectively (Fig. 6), a decrease of 58% with a significant difference in average monthly concentrations (Table 2).

Hourly concentrations of ascospores showed a significant correlation with rainfall in May 1998 (r=0.16; P<0.05) but not in May 1999 (r=0.07; P>0.05). In May 1998, there were five notable occasions when rain fell (Fig. 7). On the first (5 May), ascospores increased with the rainfall and peaked 4–6 h later. On the second occasion (6 May), about three times the amount of rain fell, or about 18 mm. The ascospores peaked 2 h later and again the next day. On 9 May, there was about 2 mm of rain, and ascospores peaked 6 h later. Tulsa was then dry for an extended period, and ascospore concentrations were negligible with the exception of a peak on the 15th. Tulsa received more rain on the 25th, and the ascospore concentrations immediately rose. Another shower occurred on the 26th, and ascospore concentrations continued to be abundant through the 29th at varying levels.

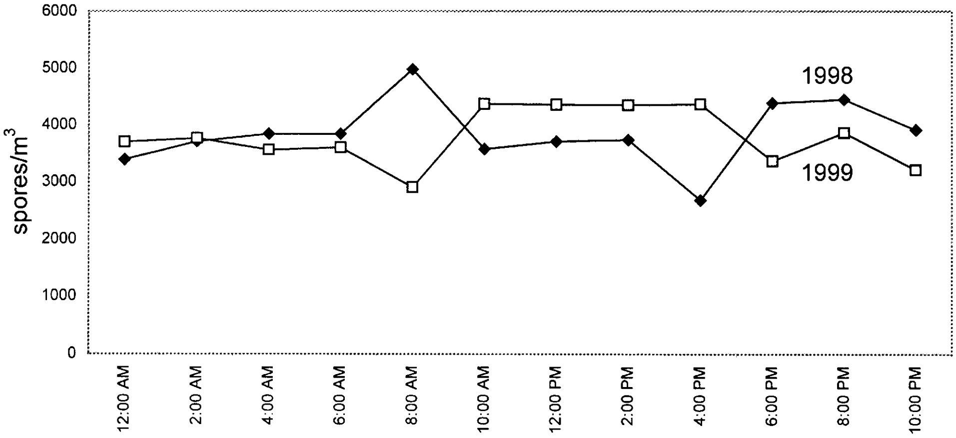


Fig. 8 Ascospore diurnal rythm for May 1998 and May 1999

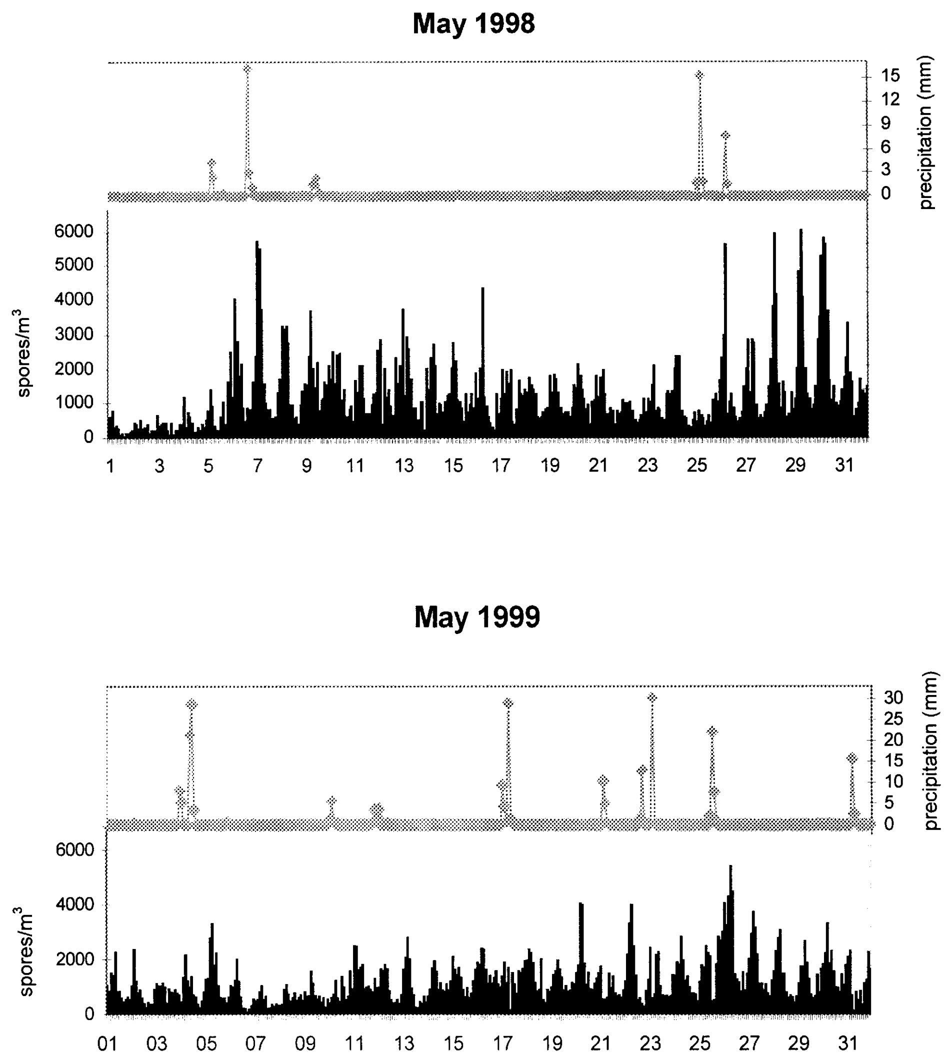


Fig. 9 Hourly airborne basidiospores and precipitation in May 1998 and May 1999

May 1999 had almost four times more rain than 1998 (Table 1). There were three 2-h intervals with 30 mm rain during May 1999 (Fig. 7). Ascospores were abundant throughout the month, with the exception of three distinct periods. In each instance when the ascospore concentration dropped off, there had been no rain for at least 2 days previously. There were only 4 days when the average daily concentration of ascospores dropped below 1,000 spores/m^3; however, the CMT of ascospores released in the 2 months differed only by 1.7%: 119,318 in 1998 and 117,278 in 1999.

The average monthly concentrations of ascospores were not significantly different over the 2 months studied (Table 2). The ascospore diurnal rhythm formed no

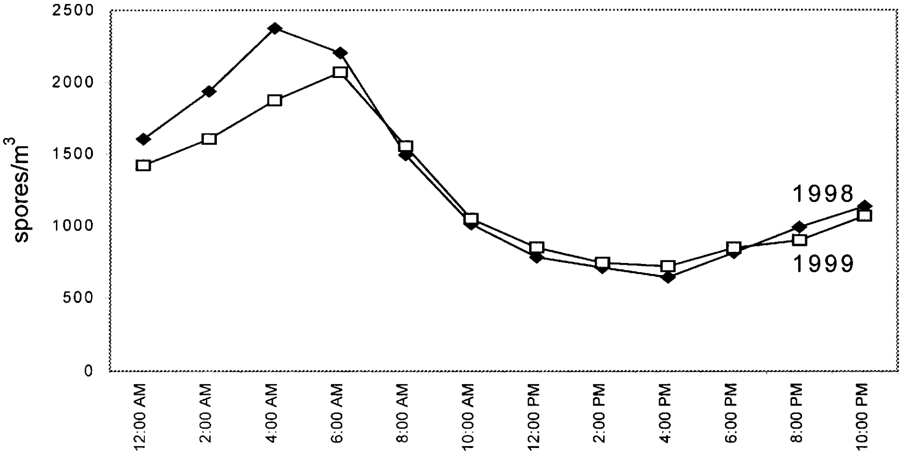


Fig. 10 Basidiospore diurnal rhythm for May 1998 and May 1999

patterns or curves in either year (Fig. 8). In addition, the fluctuations of the concentrations did not seem to depend on the time of day. The ascospores were counted as a group instead of being separated by genus; however, the most abundant types found were *Leptosphaeria.*, *Didymella*, *Venturia*, and members of the Diatrypaceae.

Basidiospores were abundant throughout both May 1998 and May 1999 (Fig. 9) and had concentrations that did not significantly differ over the 2 months (Table 2). The CMT were 40,512 and 37,922 for 1998 and 1999 respectively. On 7 May, 1998 the basidiospore concentration rose above 5,500 spores/m^3 the day after there had been over 15 mm of rain, but generally there was a longer lag time before a peak occurred in basidiospores. However, there were no significant correlations between precipitation and basidiospore levels. May 1999 showed even less of a relationship between basidiospores and rain with fairly consistent levels throughout the month. The diurnal fluctuation of spore concentrations is evident in the hourly data throughout each month (Fig. 9) and is averaged for each month in Fig. 10. The basidiospores showed a very clear diurnal rhythm. Although there was no attempt to enumerate individual genera of basidiospores, the following were the most abundant types: *Coprinus*, *Agaricus*, *Psathyrella*, *Conocybe*, and colorless basidiospores.

Other taxa studied did not make up a large percentage of the total air spora in either month. The types included *Epicoccum*, *Curvularia*, *Drechslera*, *Pithomyces*, smut spores, and other spores. *Pithomyces* and smut spores did not have significantly different concentrations during the 2 months, while the rest did (Table 2).

Multiple regression analysis was used to determine which meteorological factors could be used as predictors of spore concentrations. The correlations between the different spore types and the meteorological variables used in the regression analyses are presented in Tables 3 and 4. While all of the spore types were analyzed, only the major taxa of *Cladosporium*, ascospores and basidiospores will be discussed.

Temperature was a significant predictor for the hourly *Cladosporium* concentrations in both years, explaining 20.7% of the variability in May 1998. Pressure was also a significant factor in 1999, together predicting 11.5% of the variability in May 1999 (Table 4). Ascospores related negatively to temperature in the hourly multiple regressions for both years. May 1998 showed significant relationships for ascospores with precipitation and wind gusts, whereas the May 1999 model included dew point and wind speed as significant meteorological variables. The 1998 multiple regression accounted for 11.0% of the variability for ascospores while the 1999 hourly model accounted for only 4.8%. Both hourly basidiospore models accounted for 20% of the variation in spore levels, with a negative relationship with temperature and a positive relationship with dew point. The 1999 hourly multiple regression also included precipitation and pressure as important predictors. Regression analyses using up to 8-h time lags were also conducted with no improvement in predictive results (data not shown).

Temperature was the only meteorological variable that was a significant predictor for average daily concentrations in the 1998 multiple regression for *Cladosporium*, in a model that explained 56.1% of the variation in spore levels. Although the daily multiple regression model for *Cladosporium* in 1999 explained 38.0% of the variability, no meteorological factors were significant as predictors. The ascospores had a negative relationship with temperature and a positive relationship with dew point in the daily multiple regression for both years, with r^2=0.417 for 1998 and 0.400 for 1999. The only significant meteorological variable for basidiospores in both daily multiple regressions was dew point. This explained 35.2% of the variability for basidiospores in 1998 and 43.3% in 1999.

Discussion

The total number of spores was much greater in 1998 primarily because of the increased amount of *Cladosporium*. Because of the relationship between ascospores and rainfall (Burge 1986; Gottwald et al. 1997; Hasnain 1993), we expected to see higher ascospore concentrations during May 1999. This, in fact, did not happen.

Table 3 Multiple regression analyses of meteorological parameters with the logarithm of hourly fungal spore concentrations for May 1998 and May 1999. For estimates of wind direction, readings (degrees) from due north were converted into an ordinal scale of 1–9 for the regression analysis

Spore type	r^2	β values						
		T	Dew pt.	Precip.	Wind direction	Gusts	Pressure	Wind speed
1998								
Cladosporium	0.207*	0.2912*	0.1615*	0.0733	0.0825	–0.0567		
Alternaria	0.142*	0.3764*						
Epicoccum	0.128*	0.3609*				–0.1033*		
Curvularia	0.059*	0.1522*			0.0677		0.1478*	
Pithomyces	0.077*	0.1021	0.1037			0.0887		0.0887
Drechslera	0.121*	0.3446*		–0.0935	–0.0893		–0.1364*	
Smut spores	0.127*	0.1810*	0.1349*	0.0784	0.1100		0.0739	
Ascospores	0.110*	–0.2732*	0.1107	0.1405*	–0.0955	0.1124*		
Basidiospores	0.203*	–0.4309*	0.5714*			0.0733	0.0813	
Other	0.077*			0.1346*		0.0692	–0.0939	0.1635*
Total	0.267*		0.5001*	0.1382*				
1999								
Cladosporium	0.115*	02302*			–0.0729		0.2666*	
Alternaria	0.148*	0.5439*	–0.3345*		–0.1257	0.0784		–0.2854*
Epicoccum	0.029*	0.2076*	–0.1587*		–0.0988			
Curvularia	0.003						–0.0571	
Pithomyces	0.017						–0.0664	0.0897
Drechslera	0.109*	0.4605*	–0.3166*		–0.1515*		–0.0737	–0.1159
Smut spores	0.102*	0.1433*	–0.3315*	–0.0973	–0.1263*		–0.0144*	
Ascospores	0.048*	–0.2381*	0.2170*		0.0715	–0.0822	0.1211	0.1956*
Basidiospores	0.197*	–0.3090*	0.4468*	–0.1241*	0.0968		0.2826*	
Other	0.043*			0.1579*		0.1083*		
Total	0.149*		0.3367*	–0.0526			0.2331*	

*Significant r^2 and β values ($P<0.05$)

Table 4 Multiple regression analyses of meteorological parameters with log of daily fungal spore concentrations for May 1998 and May 1999

Spore type	r^2	β values				
		T	Dew pt.	Precip.	Pressure	Wind speed
1998						
Cladosporium	0.561*	0.666*		–0.257	–0.160	
Alternaria	0.412*	0.536*		–0.263		
Epicoccum	0.306*	0.374*		–0.340*		
Curvularia	0.360*	–0.467	0.811*	–0.284	0.377*	
Pithomyces	0.434*		0.368	–0.198		0.313
Drechslera	0.337*	0.635*		–0.356	–0.316	–0.374
Smut spores	0.497*	0.967*	–0.601	0.221		0.316
Ascospores	0.417*	–0.905*	0.734*	0.267		
Basidiospores	0.352*		0.594*			
Other	0.156			0.382*		0.310
Total	0.517*		0.810*			–0.206
1999						
Cladosporium	0.380*	0.484	–0.140	–0.213	0.475	0.011
Alternaria	0.337	1.356*	–1.297*	0.017	0.186	–0.339
Epicoccum	0.283	0.313	–0.645	–0.148	0.362	0.270
Curvularia	0.134	0.215	–0.263	–0.227	–0.375	–0.135
Pithomyces	0.223	0.034	–0.421	0.106	0.046	0.427
Drechslera	0.322	0.528	–0.571	–0.436*	–0.041	–0.174
Smut spores	0.395*	1.035*	–1.480*	–0.043	0.198	0.285
Ascospores	0.400*	–1.064*	1.120*	0.331	0.070	0.073
Basidiospores	0.433*	0.134	0.016*	0.503	0.707	0.171
Other	0.084	–0.183	0.349	–0.131	0.068	0.222
Total	0.361*	–0.594	0.972*	0.242	0.367	0.055

*Significant r^2 and β values ($P<0.05$)

Although the temporal distribution of ascospores was different for the 2 months, the CMT of spores released was very consistent. It is possible that, in the dry month (May 1998), the ascospores were mature and primed, and any occurrence of moisture was enough to release a large quantity of the spores at once. Since there was almost constant moisture in May 1999, the ascospores may have been released as they matured in smaller numbers but over the entire month instead of on selected days. (The multiple regression models all showed a negative relationship between ascospores and temperature, and a positive relationship with either dew point or precipitation.) It is expected that temperature would be negatively related to ascospore concentrations since temperature is frequently lower during rain events; however, Levetin et al. (1998) found positive relationships between ascospores and temperature, relative humidity and rainfall in 1994 and 1995. The inconsistency of the temperature relationships between the two studies may be due to the seasonal pattern of the ascospores because the earlier study followed the spores over the course of 2 years instead of selecting a particular month to study.

The hourly graphs of precipitation and ascospores (Fig. 7) suggest why dew point was more significant than actual rainfall in three of the models. Sometimes the ascospores appeared directly with the first rainfall, while other times there was a delay for as long as 8 h, explaining why regression analyses did not improve with the time lag. Some of the difference may be the result of not distinguishing between the different types of ascospores. Ascospores such as *Leptosphaeria* and *Ophiobolus* are found within minutes of rainfall and concentrations remain high as long as the rain continues, while other types are found primarily at night in response to low temperatures and high humidity (Burge 1986). A positive relationship has been found between light intensity and *Venturia inequalis*, meaning that spore release for *Venturia* was suppressed during darkness (Gadoury et al. 1998). For rain data, we used the amount of rain over a 2-h period without taking into account how forcefully the drops were falling or whether the presence of precipitation alone (and not the amount) was important for spore release. In addition, brief periods of very heavy rain might cleanse ascospores from the atmosphere. This might affect ascospore concentrations differently from steady light rain falling for 2 h. More variability might have been explained if we had taken these other factors into consideration.

There was a very small but not significant difference in the number of basidiospores during the 2 months. The majority of basidiospores are produced by fleshy fungi (mushrooms, bracket fungi, and puffballs). These fruiting bodies are found in the area from late spring through fall when environmental conditions are adequate for their development. It seems that the moisture in May 1998 was adequate for the development of fruiting bodies and release of spores. The fact that their diurnal rhythm was so predictable and consistent over both months suggests that basidiospores rely less on precipitation levels than do other spore types. Once their moisture requirement has been met, they are neither helped nor hindered by other meteorological factors. This predictable diurnal rhythm with a predawn peak and afternoon depression has been well documented (Burge 1986). A positive relationship with dew point occurred in all four regression models, indicating that the atmospheric moisture was more important than individual precipitation events. The hourly multiple regression models (Table 3) explained less variability than did the daily regression models (Table 4), but this may have been due to the fact that the hourly models do not take into account the diurnal rhythms of the basidiospores and other taxa.

For *Cladosporium*, the most consistently significant predictor in the regression analysis was temperature. The only multiple regression model that did not show this relationship was the May 1999 daily regression. Hasnain (1993) also found a strong correlation between maximum temperature and *Cladosporium* concentrations. Dew point and pressure might play secondary roles in *Cladosporium* release but, as the atmosphere warmed, more *Cladosporium* seemed to be found in the atmosphere. The warmest day in either month had a high temperature of 34.4°C and an average temperature of 28.3°C. In addition, this particular day showed the peak concentration of *Cladosporium* spores for the combined study period. Other studies have found that *Cladosporium* concentrations increase briefly directly before and after rainfall (Hjelmroos 1993), but this was not evident in the data presented here.

Temperature seemed to be the best predictor for *Alternaria*, appearing with a positive relationship in all four regressions. Dew point appeared significant in both of the 1999 regressions with a negative relationship, fitting in with our expectations that *Alternaria* would be most abundant on hot, dry days. However, previous studies done by Timmer et al. (1998) and Katial et al. (1997) have found no obvious statistically significant relationships between *Alternaria* and meteorological factors.

For smut spores, temperature was an important meteorological predictor in all multiple regressions, with dew point negatively related in three of the models (although only significant in two). It would be expected that, as the air dried out, more smuts would be released since they are part of the dry-air spora, but the opposite effect seemed to occur with the hourly data in May 1998. Dew point was positively related to smut spore concentrations during that period. A study by Crotzer and Levetin (1996) showed smuts to be negatively correlated with dew point and precipitation and positively with temperature. The positive relationship with dew point in the hourly May 1998 data may reflect a higher than average dew point during that month (Table 1).

In summary, the dry month of May 1998 showed significantly higher concentrations of *Cladosporium* and total spores than May 1999, while ascospore and basidiospore levels in the Tulsa atmosphere were very consistent. However, the distribution and abundance of ascospores on any given day was very different for the

2 months. May 1998 had days with large peaks of ascospores as well as days of small concentrations, while May 1999 had moderate concentrations throughout the month. Temperature and dew point seemed to be the most important meteorological factors in overall spore release.

Acknowledgements This research was made possible, in part, by a National Science Foundation–Experimental Partnership to Stimulate Competitive Research grant (project number EPS9550478), which provided funds to enhance the Oklahoma Mesonet. Funding was also provided by the National Science Foundation Research Experience for Undergraduates and the Tulsa Undergraduate Research Challenge. The authors would also like to thank Pete Van de Water and Mary Larsen–Purvis for their assistance. The research conducted complies with federal laws of the United States of America.

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