Int J Biometeorol
DOI 10.1007/s00484-011-0508-4

SHORT COMMUNICATION

Footprints of climate change in US national park visitation

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Received: 5 July 2011 / Revised: 30 September 2011 / Accepted: 25 October 2011

Abstract Climate change has driven many organisms to shift their seasonal timing. Are humans also shifting their weather-related behaviors such as outdoor recreation? Here we show that peak attendance in US national parks experiencing climate change has shifted 4 days earlier since 1979. Of the nine parks experiencing significant increases in mean spring temperatures, seven also exhibit shifts in the timing of peak attendance. Of the 18 parks without significant temperature changes, only 3 exhibit attendance shifts. Our analysis suggests that humans are among the organisms shifting behavior in response to climate change.

Keywords Climate change · Human-environment interaction · Phenological shift · Phenology · Recreation · Spring · Tourism

Introduction

Shifts in phenology—the timing of periodic biological events—provide the bulk of the evidence that organisms are responding to recent climate change (Parmesan 2006; Parmesan and Yohe 2003; Parry et al. 2007; Root et al. 2003). Observed shifts include plants flowering (Inouye 2008; Miller-Rushing and Primack 2008; Primack et al. 2009; Willis et al. 2008), birds migrating and breeding (Visser and Both 2005), butterflies flying (Roy and Sparks 2000), and mammals emerging earlier (Inouye et al. 2000). These shifts to earlier warm-weather activities follow from spring warming over recent decades (Menzel et al. 2006; Parry et al. 2007). Have analogous shifts also occurred in patterns of human activity?

Many human activities, including leisure, are linked tightly to either cold winter weather or hot summer weather (Scott and Lemieux 2010). We examine whether the timing of national park attendance has shifted coincidently with recent warming. The link between climate and outdoor recreation is well established (Scott and Lemieux 2010) and has been used to examine potential future climate change impacts on recreation (Scott et al. 2008) such as shifts in seasonality (Amelung et al. 2007; Scott et al. 2004). However, few studies have examined whether seasonal shifts have already resulted from recent climate change (e.g., Galeotti et al. 2004).

Most potential covariates of national park visitation (e.g., population, economic trends, travel costs, and preferences) are expected to act at interannual rather than monthly timescales and thus to influence the magnitude rather than seasonality of park attendance. Our analysis focuses on assessing the timing and amplitude of the annual seasonal trend and should therefore be robust to covariates. Shifts in park visitation may be constrained by fixed holidays such as school vacations, but these constraints should not bias temporal trends. These constraints are likely particularly acute for long-distance visitors (Richardson and Loomis 2004). This focus on seasonality differs from most assessments of the relationship between recreation or tourism and climate, which use regressions to predict recreation or tourism magnitude as a function of climate and other covariates (Scott and Lemieux 2010). However, we feel that

Electronic supplementary material The online version of this article (doi:10.1007/s00484-011-0508-4) contains supplementary material, which is available to authorized users.

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Published online: 23 November 2011

our approach provides a robust assessment of seasonality shifts as the importance of covariates are likely to shift over time. We link recent temperature increases to shifts in human behavior via establishing a relationship between the monthly park attendance and air temperature and documenting corresponding shifts in temperature and peak park visitation over time.

Materials and methods

We retrieved monthly data for recreational visits to 55 parks during 1979–2008 from the National Park Service (http://www.nature.nps.gov/stats/). Monthly air temperature data was downloaded from the National Climate Data Center United States Historical Climatology Network (HCN, http://www.ncdc.noaa.gov/oa/climate/research/ushcn/). We used mean spring (April–May) temperature data as spring advancement is characteristic of recent climate change and is the best predictor of phenological advancement for many organisms (Menzel et al. 2006; Parry et al. 2007) We used data from the weather station nearest the park's geographic centroid except in cases where a nearby weather station was more representative (e.g., a montane station verses a low-elevation urban area). In no case did our use of a more representative weather station influence the significance our results.

We used a direct Fourier transformation to describe the seasonal signal in monthly national park attendance as sine and cosine curves (R code provided in SI Appendix). The strength of seasonality in the data was estimated as the ratio of the square root sum of squares of sine- and cosine-adjusted averages to the unadjusted average. Theta, the amplitude of the sine function describing the seasonal signal, was calculated as the arc-tangent of the sine- and cosine-adjusted averages of the data. The month corresponding to the peak of the sine function was calculated as theta*12/2π +1. This metric represents the timing of peak park attendance and is the response variable in our regressions (spring temperature is the predictor variable). Our analysis focuses on shifts in the seasonal distribution of visitation rather than changes in the shape of the distribution (such as a broadening of the distribution due to increased visitation in shoulder seasons).

Because we are interested in the seasonal trend, we excluded those parks that exhibited limited seasonality in park attendance (mean seasonality<0.20). We omitted parks with fewer than 100,000 annual visitors in 1979 to preclude seasonal shifts due to expanded visitation. We additionally excluded parks with seasonal visitation patterns determined by user limits (e.g., cave tour reservations). Our final dataset included 27 of the initial 55 parks. Significance is reported at the level of $P<0.05$ for all analyses, but should be interpreted conservatively due to our comparisons across parks.

Results

The timing of peak national park attendance has advanced since 1979. While all parks experience increasing attendance in warm weather, the strength and shape of this relationship varies (Fig. S1). Given increased attendence in warm weather, we expect that increasing spring temperatures over recent decades will result in earlier peak attendance. Of the 27 national parks (NP), 15 exhibit neither a significant shift in temperature nor attendance, while 7 parks have experienced significant shifts in both (Table 1). Two parks show only a temperature shift and three parks show only an attendance shift. The proportion of parks that exhibit either neither (0.55) or both (0.26) shifts are substantially greater than expected randomly (0.42 and 0.12, respectively) based on the proportion of parks with temperature and attendance shifts (χ^2 test; χ^2=9.6, P=0.02).

Peak attendance has shifted an average of 4.6 days (6.3 days median) earlier over the last three decades across the seven parks with both shifts. For example, the peak attendance of Grand Canyon NP shifted from 4 July in 1979 to 24 June in 2008, and that at Mesa Verde NP has shifted from 10 July to 1 July over the corresponding time period (Fig. 1). Four of these parks shifted towards earlier peak attendance. The remaining three parks are slickrock deserts in Utah (Bryce Canyon, Captial Reef, and Zion) and are best fit by concave-downward polynomials (Table 1). Thus, peak attendance shifted later initially but then shifted earlier as temperatures continued to increase. Closer examination of the data suggests that an increase in fall attendance accounts for the initial shift toward later attendance. We note that all three of these parks are proximate and may thus show similar visitation trends. The peak attendance of Capital Reef NP shifted from 23 June in 1979 to 1 July in 2008 (linear regression, Fig. 1).

Several of the parks that exhibit only one of the expected two shifts have special circumstances. Among the three parks that exhibit only an attendance shift is Theodore Roosevelt NP, where visiting the historical ranch drives visitation in addition to outdoor recreation. Sequoia NP's shift toward earlier peak attendance becomes non-significant (P=0.50) and has a very shallow estimated slope (estimate±SE=−0.003±0.004) upon excluding data before 1983, which have anomolously late peak attendance. The shift to earlier peak attendance in 1983 is approximately concurrent with increases in park concessions (Dilsaver and Tweed 1990). Several weather stations documenting recent temperature increases in Rocky Moun-

Table 1 Estimates (*Est*) and standard errors (*se*) along with *F*, *P*, and r^2 values for linear regressions between annual temperature and peak attendance with year. For the four Utah desert parks, we additionally present polynomial regressions

			Temperature~year					Attendance~year						
Code	Park		Est	se	*F*	*P*	r^2	Est	se	Est	se	*F*	*P*	r^2
ACAD	Acadia		−0.023	0.019	1.5	0.234	0.05	0.0004	0.002			3.7	0.065	0.12
ARCH	Arches		0.062	0.022	7.8	0.009	0.22	0.00	0.002			0.0	0.917	0.00
		polynomial						0.0012	0.105	−0.207	0.105	2.0	0.161	0.13
BADL	Badlands		−0.004	0.030	0.0	0.906	0.00	−0.001	0.001			0.4	0.541	0.01
BLCA	Black Canyon of the Gunnison		0.056	0.021	6.8	0.015	0.19	−0.003	0.002			2.1	0.154	0.07
BRCA	Bryce Canyon		0.064	0.025	6.5	0.016	0.19	0.002	0.002			0.8	0.384	0.03
		polynomial						0.097	0.092	−0.332	0.092	7.1	0.003	0.34
CARE	Capitol Reef		0.059	0.023	6.9	0.014	0.20	0.009	0.003			8.0	0.008	0.22
		polynomial						0.417	0.128	−0.405	0.128	10.3	0.000	0.43
CRLA	Crater Lake		0.014	0.026	0.3	0.587	0.01	0.001	0.003			0.2	0.699	0.01
GLAC	Glacier		−0.019	0.022	0.7	0.394	0.03	0.000	0.002			0.0	0.861	0.00
GRCA	Grand Canyon		0.057	0.023	6.4	0.017	0.19	−0.012	0.003			18.1	0.000	0.39
GRTE	Grand Teton		0.025	0.026	0.9	0.345	0.03	−0.003	0.002			2.8	0.105	0.09
GRSA	Great Sand Dunes		0.057	0.018	10.0	0.004	0.026	−0.012	0.002			30.4	0.000	0.52
GRSM	Great Smoky Mountains		0.034	0.018	3.5	0.070	0.11	0.000	0.002			0.1	0.801	0.00
KICA	Kings Canyon		0.012	0.032	0.1	0.720	0.00	−0.008	0.005			2.9	0.100	0.09
LAVO	Lassen Volcanic		−0.017	0.026	0.4	0.519	0.01	−0.003	0.003			1.0	0.335	0.03
MEVE	Mesa Verde		0.058	0.019	8.9	0.006	0.24	−0.009	0.002			28.3	0.000	0.50
MORA	Mount Rainer		−0.018	0.025	0.5	0.485	0.02	0.004	0.002			2.2	0.146	0.07
OLYM	Olympic		−0.007	0.018	0.1	0.705	0.01	0.001	0.002			0.2	0.693	0.01
PEFO	Petrified Forest		0.052	0.021	6.1	0.020	0.18	−0.007	0.003			7.8	0.009	0.22
REDW	Redwood		0.026	0.019	1.9	0.181	0.06	−0.007	0.004			3.4	0.077	0.11
ROMO	Rocky Mountain		0.031	0.021	2.3	0.139	0.08	−0.006	0.001			17.6	0.000	0.39
SEQU	Sequoia		0.012	0.032	0.1	0.720	0.00	−0.009	0.003			6.1	0.020	0.18
SHEN	Shenandoah		0.003	0.021	0.0	0.906	0.00	0.002	0.003			0.2	0.626	0.01
THRO	Theodore Roosevelt		0.001	0.035	0.0	0.986	0.00	0.009	0.002			22.3	0.000	0.44
VOYA	Voyageus		−0.006	0.037	0.0	0.876	0.00	0.007	0.004			3.5	0.072	0.11
YELL	Yellowstone		0.012	0.027	0.2	0.670	0.01	−0.002	0.001			3.1	0.090	0.10
YOSE	Yosemite		0.011	0.031	0.1	0.731	0.00	0.001	0.003			0.0	0.850	0.00
ZION	Zion		0.078	0.027	8.5	0.007	0.23	−0.007	0.003			4.6	0.040	0.14
		polynomial						−0.310	0.128	−0.371	0.128	7.1	0.003	0.35

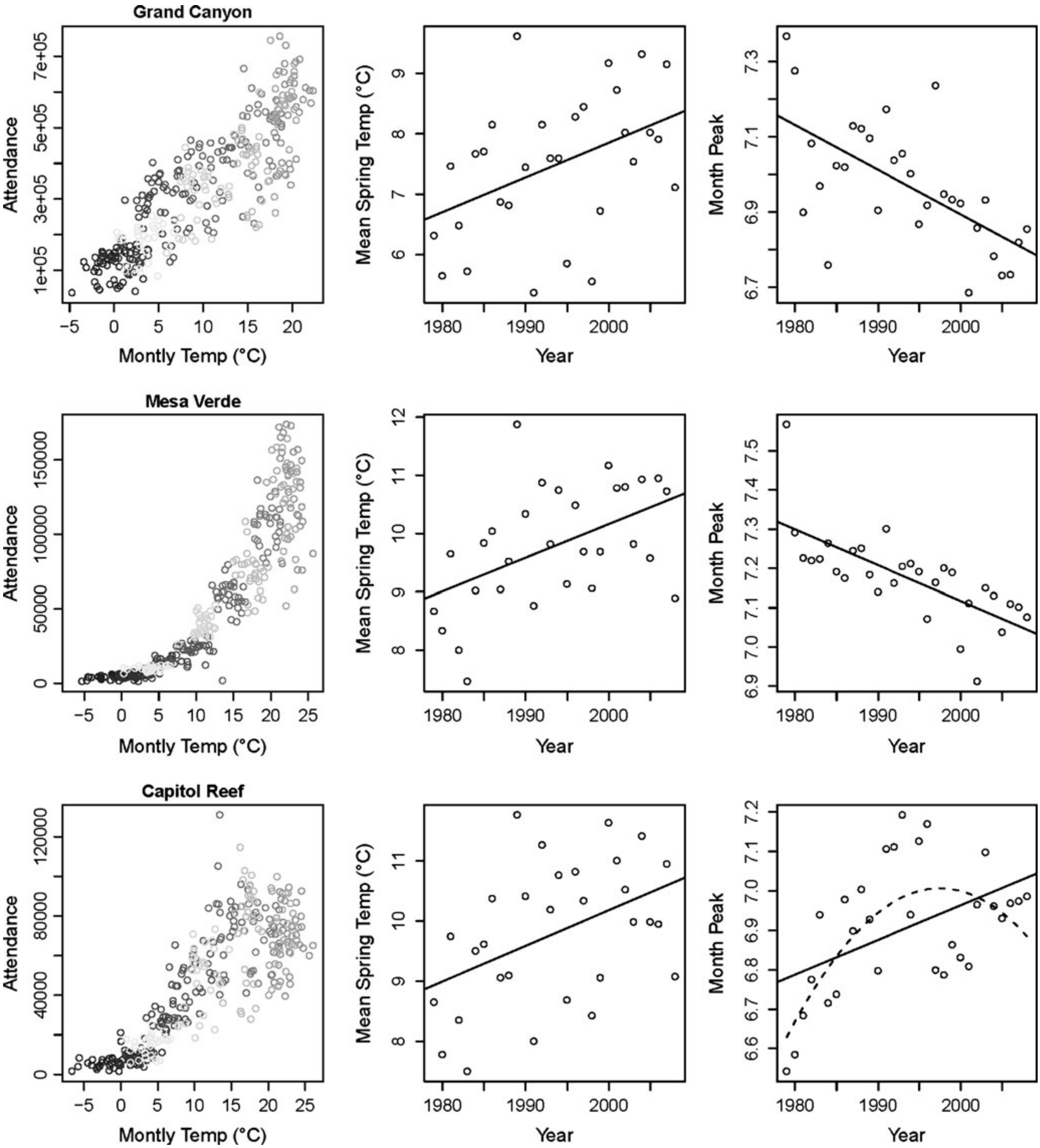

Fig. 1a–c Examples of two parks that shift towards earlier and one park that shifts toward later peak attendance. We show that **a** park attendance increases with increasing monthly temperatures (the horizontal scatter is due to temporal changes); **b** mean spring temperatures have increased over time; and **c** the monthly peak of park attendance has shifted over time. Linear regressions significant at $P<0.05$ are shown. We additionally show a polynomial (*dashed*) regression for Capital Reef. In the *left panel*, lighter grays indicate earlier months. Month peak depicts fractional months. See Fig. S1 for additional parks

tain NP(Hoffman et al. 2007) are consistent with the observed shift toward earlier peak attendance. Rocky Mountain NP lacks a representative weather station in the HCN. The closest weather station, which we use, is in the city of Boulder. A nearby weather station in Fort Collins (ID:53005) does show a significant increase in temperature over the study period (estimate±SE=0.056±0.022, $F[1,28]=6.6$, $P=0.016$, $r^2=0.16$; Fig. S1). Of the two parks that exhibit a significant temperature increase only, the Black Canyon of the Gunnison NP and Arches NP show a suggestive but non-significant shift toward earlier peak attendance ($P=0.15$) and a concave-downward polynomial trend in attendance ($P=0.16$), respectively.

Discussion

The spring advancement in national park attendance (1.5 days decade^{-1} for parks experiencing both temperature and attendance shifts) is comparable to but less than average values across other taxa (2.3 to 5.1 days decade^{-1}) (Parmesan and Yohe 2003; Root et al. 2003). The consistency of our response across parks is similar to that observed across species. Of the nine parks that have experienced significant temperature increases since 1979, 78% exhibit shifts in the timing of peak attendance; 71% of species exhibited a phenological shift (Parmesan and Yohe 2003).

The correlative nature of our evidence prevents attributing causation. Yet, our evidence complements that rapidly accumulating for other organisms showing behavioral shifts in the direction expected in response to climate change (Parmesan 2006). Together, this evidence suggests that ecosystems have already been altered by increasing temperatures associated with anthropogenic climate change. Our demonstration of recent shifts in the seasonality of park visitation confirms the importance of projections of future shifts in park visitation in response to climate change (Jones and Scott 2006; Richardson and Loomis 2004; Scott et al. 2007). The National Park Climate Friendly Parks Program—and the National and State Park agencies more broadly—may need to plan for shifts in visitation in additional to wildlife responses. While the occurrence of global warming continues to be debated by the public, our analysis suggests that we are already responding to climate change and highlights that climate change is likely to impact both ecosystem and human phenology.

Acknowledgments We thank the National Park Service for providing visitation data. Thanks to J. Bruno, C. Costello, M. Hastings, A. Hurlbert, J. Kingsolver, D. McGlinn, and J. Stegen for comments on the analyses and manuscript.

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