Broadscale Assessment of Groundhog (*Marmota monax*) Predictions of Spring Onset No Better than Chance

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ABSTRACT: Groundhog Day is a widespread North American ritual that marks the onset of spring, with festivities centered around animals that humans believe have abilities to make seasonal predictions. Yet, the collective success of groundhog *Marmota monax* prognosticators has never been rigorously tested. Here, we propose the local climate-predicted phenology of early blooming spring plants (Carolina spring beauty, or *Claytonia caroliniana*, which overlaps in native range with groundhogs) as a novel and relevant descriptor of spring onset that can be applied comparatively across a broad geographical range. Of 530 unique groundhog-year predictions across 33 different locations, spring onset was correctly predicted by groundhogs exactly 50% of the time. While no singular groundhog predicted the timing of spring with any statistical significance, there were a handful of groundhogs with notable records of both successful and unsuccessful predictions: Essex Ed (Essex, Connecticut), Stonewall Jackson (Wantage, New Jersey), and Chuckles (Manchester, Connecticut) correctly predicted spring onset over 70% of the time. By contrast, Buckeye Chuck (Marion, Ohio), Dunkirk Dave (Dunkirk, New York), and Holland Huckleberry (Holland, Ohio) made incorrect predictions over 70% of the time. The two most widely recognized and long-tenured groundhogs in their respective countries—Wiarton Willie (Canada) and Punxsutawney Phil (United States)—had success rates of 54% and 52%, respectively, despite over 150 collective guesses. Using a novel phenological indicator of spring, this study determined, without a shadow of a doubt, that groundhog prognosticating abilities for the arrival of spring are no better than chance.

SIGNIFICANCE STATEMENT: The groundhog has long been considered North America's premiere prophet for projecting the onset of spring. Yet, the accuracy of groundhog predictions with few exceptions has remained overlooked and untested. By using a straightforward indicator of spring across the range of groundhog locations—the climate-inferred flowering date of Carolina spring beauty, one of North America's earliest spring blooms—our results indicate that groundhog predictions have odds that are no better than a coin toss. Of 530 guesses, groundhogs managed a success rate of exactly 50%, and not a single groundhog of the 33 tested stood out as being meaningfully successful at predicting the onset of spring. While groundhogs provide an enjoyable ritual, rodent forecasters should stop hogging the spotlight.

KEYWORDS: Forecast verification/skill; Numerical weather prediction/forecasting; Seasonal forecasting

1. Introduction

Accurately predicting the onset of spring has long been a source of speculation in human culture and continues today, primarily for agricultural purposes. Having both cue and clue of when snow or rains will recede to open fields for seeding can mean the difference between a boom or bust for farmers and the societies and economies they support. In lieu of highly complex weather models and plant phenology, Indigenous and settler cultures across the globe often used faunal biological indicators as oracles of the onset of spring (Turner and Clifton 2009; Pareek and Trivedi 2011; Risiro et al. 2012). For example, clams are said to predict inclement weather by producing more bubbles than usual, and cows licking their forefeet are one of 11 different bovine-related signs of rain (Wallisch 1999). Similarly, it has been observed that sugar gliders induce torpor in response to inclement weather (Nowack et al. 2015). Despite this diversity of weather pattern prophets, the groundhog *Marmota monax* appears to have claimed the throne as the appointed predictor of spring onset in the United States and Canada.

For over 100 years, a growing collection of North American villages, towns, and cities have used groundhogs to predict the early or late arrival of spring. The tradition states that if, on removal from its burrow, a groundhog "sees its shadow,"

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spring will come late; alternatively, if the groundhog does not see its shadow, spring will come early. Groundhog Day is an exclusively North American holiday, introduced by European immigrants to Pennsylvania as a variant of an ancient Christian celebration of Candlemas, which marked the midway point between the winter solstice and the spring equinox (Yoder 2003). The original Candlemas tradition portended 40 more days of winter if the weather on this midway point was sunny. On the basis, presumably, of an apparent overabundance of groundhogs in the region at the time, these newly minted Pennsylvanians altered the traditional celebration by including the use of this large rodent and the shadow it casts on the assigned day as the harbinger of spring. The first celebrated instance of Groundhog Day was in Punxsutawney, Pennsylvania, in 1887. In regions where this holiday has been celebrated for decades, these weather-predicting groundhogs have become well known celebrities, expanding beyond the original Punxsutawney Phil (Pennsylvania) to include other notable members of the genus *Marmota* such as Wiarton Willie (Ontario, Canada), Buckeye Chuck (Ohio), and Shubanacadie Sam (Nova Scotia, Canada; Yoder 2003).

Notwithstanding, the accuracy of groundhog forecasts has rarely been questioned and has never once been comprehensively assessed, even with the multitude of groundhogs now purportedly forecasting weather across North America. Possibly because of his big-hog status (and long-term data record), Punxsutawney Phil has had his predictions most heavily evaluated. Using daily minimum and maximum temperatures and snowfall depth from the nearest weather station, Aaron et al. (2001) analyzed the accuracy of Phil's forecasting abilities from 1950 until 1999. For 6 weeks following 2 February, if the average daily minimum and maximum temperatures were significantly greater than, and the average daily snowfall was significantly less than, those for the 6 weeks before 2 February, the authors considered it to be an early spring (Aaron et al. 2001). With this method, the authors found that Phil made accurate predictions 70% of the time (Aaron et al. 2001). Other sources, which use different and largely ambiguous thresholds of prognosticating success, tell a different tale; the U.S. National Oceanic and Atmospheric Administration (NOAA) indicates that Punxsutawney Phil was correct only 40% of the time (NOAA 2020), and the *Old Farmer's Almanac* reports that groundhogs are 50% accurate when forecasting the seasons (Thomas 1997), although no quantitative analyses are provided to substantiate these claims. Some groundhogs like General Beauregard Lee (Jackson, Georgia) self-report accuracy rates of 99% (Yoder 2003).

Predictions by Aaron et al. (2001), which form the most comprehensive assessment of groundhog predictions to date, fall short in two critical ways: 1) predictive success was measured for only a single groundhog, Punxsutawney Phil; and 2) the methods that the authors used do not permit evaluation of groundhogs across latitudinal and longitudinal scales because of climatic variance that groundhog forecasters encounter across their "natural" range (i.e., snow accumulation is unlikely to be a relevant metric at the southern end of groundhog distributions).

As a more objective and broadly applicable approach to evaluating the onset of spring, we propose the use of peak flowering timing in a widely distributed spring-blooming plant. The phenological link between ambient temperature, plant development, and seasons is well established (Piao et al. 2019) and has been used to assess the timing of spring and summer across continental Europe (Menzel et al. 2006). In the current study, we chose to use the climate-predicted phenology of one of North America's earliest spring ephemerals, the Carolina spring beauty, or *Claytonia caroliniana*, as a phenological proxy of the arrival of spring and therefore as a means of evaluating the predictive capacity of groundhogs. The geographic distribution of *C. caroliniana* overlaps substantially with the distribution of groundhogs, including those involved in predicting the onset of spring (Fig. 1).

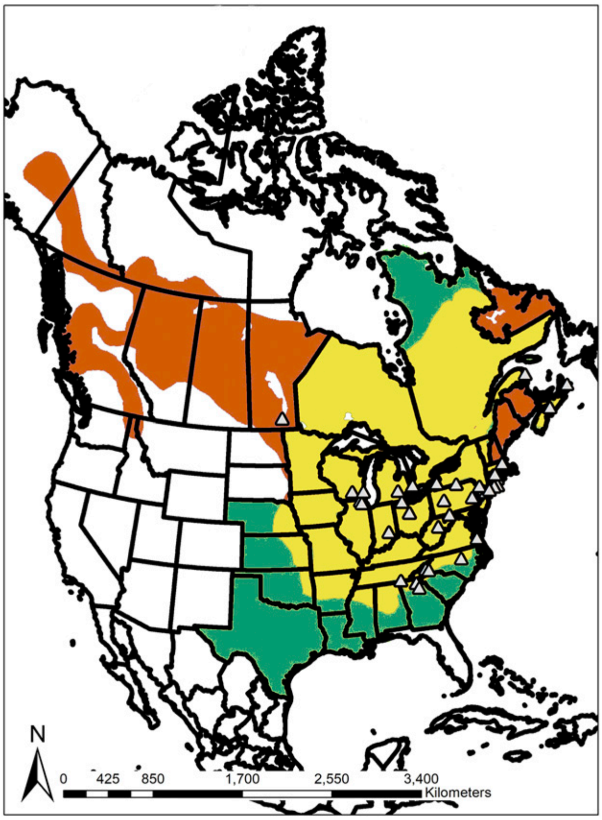

FIG. 1. Native habitat distribution of groundhogs (brown shading) as well as the spring ephemeral Carolina spring beauty (green shading) in North America. Groundhog and Carolina spring beauty co-occurrence is indicated in yellow shading, and gray triangles indicate the locations of prognosticating groundhogs.

Our goal for this study was to conduct a phenological assessment that would provide a definitive and comprehensive assessment of the spring prognostication abilities of groundhogs distributed across North America using currently available data. Our specific objectives were 1) to evaluate whether groundhog predictions were different from random chance; 2) to determine whether latitude or country of origin influenced prediction success rate; and 3) to determine whether, for the groundhogs with sufficient long-term records, there was any

TABLE 1. The identity, location, and surrounding human population size during the most recent census for the 33 prognosticating groundhogs involved in this meta-analysis, sorted by latitude.

Groundhog name	Lat	Lon	Country	Province/state	Town
General Beauregard Lee	34.1334	−83.5666	United States	Georgia	Jackson
Chattanooga Chuck	35.0456	−85.3097	United States	Tennessee	Chattanooga
Grady the Groundhog	35.4393	−82.2465	United States	North Carolina	Chimney Rock
Nibbles	35.5951	−82.5516	United States	North Carolina	Asheville
Sir Walter Wally	35.7796	−78.6382	United States	North Carolina	Raleigh
Chesapeake Chuck	37.0696	−76.4798	United States	Virginia	Newport News
French Creek Freddie	38.8857	−80.2973	United States	West Virginia	French Creek
Grubby the Groundhog	39.3039	−85.7714	United States	Indiana	Hope
Western Maryland Murray	39.6478	−78.7628	United States	Maryland	Cumberland
Staten Island Chuck	40.5852	−74.1338	United States	New York	Staten Island
Buckeye Chuck	40.5889	−83.1265	United States	Ohio	Marion
Malverne Mel	40.6773	−73.6718	United States	New York	Malverne
Holtsville Hal	40.8154	−73.0451	United States	New York	Holtsville
Quigley	40.8232	−72.6095	United States	New York	Quogue
Punxsutawney Phil	40.9437	−78.9709	United States	Pennsylvania	Punxsutawney
Stonewall Jackson	41.2448	−74.6197	United States	New Jersey	Wantage
Essex Ed	41.3504	72.4052	United States	Connecticut	Essex
Holland Huckleberry	41.6196	−83.7078	United States	Ohio	Holland
Cider	41.7697	−72.7444	United States	Connecticut	West Hartford
Chuckles	41.7759	−72.5215	United States	Connecticut	Manchester
Lawrenceville Lucy	41.9968	−77.1270	United States	Pennsylvania	Lawrenceville
Buttercup	42.0981	−88.2829	United States	Illinois	West Dundee
Woodstock Willie	42.3147	−88.4488	United States	Illinois	Woodstock
Ms. G	42.4259	−71.3039	United States	Massachusetts	Lincoln
Dunkirk Dave	42.4819	−79.3332	United States	New York	Dunkirk
Woody	42.6073	−83.9294	United States	Michigan	Howell
Oil Springs Ollie	42.7838	−82.1195	Canada	Ontario	Oil Springs
Jimmy the Groundhog	43.1836	−89.2137	United States	Wisconsin	Sun Prairie
Wiarton Willie	44.7420	−81.1408	Canada	Ontario	Wiarton
Shubenacadie Sam	45.0880	−63.4020	Canada	Nova Scotia	Shubenacadie
Two Rivers Tunnel	46.1085	−60.1601	Canada	Nova Scotia	Huntington
Fred la Marmotte “Petit”	48.5135	−64.4008	Canada	Quebec	Val d’Espoir
Winnipeg Willow	49.8951	−97.1384	Canada	Manitoba	Winnipeg

evidence that predictions of late springs were more common under climate warming currently observed in both North America and globally since the middle of the last century (Pachauri et al. 2014).

2. Methods

a. Natural history of groundhogs and Carolina spring beauty

Groundhogs (*Marmota monax*) are among North America’s largest rodents (2–5 kg) and are found broadly across Canada and throughout the northeastern and southeastern United States (Burt and Grossenheider 1976). They are solitary burrowing mammals whose home ranges consist of open areas such as fields, clearings, open forests, or rocky slopes. Similar to other hibernating squirrels, groundhogs undergo bouts of torpor through winter months where they lower their heart rate and body temperature to conserve energy (Ruf and Geiser 2015). Whereas Groundhog Day occurs annually on 2 February, groundhogs typically emerge from hibernation and their burrows in March, or even later in northern latitudes, where mating is often the first order of business (Zervanos et al. 2010). The onset of hibernation in groundhogs is caused by a combination of cool temperatures and lack of food availability (Davis 1967), and emergence from burrows appears to be related to circadian rhythms and aboveground temperature cues (Davis 1977).

The Carolina spring beauty (*C. caroliniana*) is among the earliest spring ephemerals in North America (Lehmberg et al. 2020, manuscript submitted to *Can. Field Nat.*). It is widely distributed across eastern North America, from the southern states of Alabama and Georgia through to the northern Canadian provinces of Ontario, Quebec, and the Maritimes (Miller and Chambers 2006), highly similar to the distribution of groundhogs (Fig. 1). The required annual cumulative growing degree-days (beginning 1 January) above 0°C (GDD_0) value for *C. caroliniana* to bloom was recently calculated and reported to be 129° ± 17°C (Lehmberg et al. 2020, manuscript submitted to *Can. Field Nat.*).

b. Groundhog data acquisition

A list of historical and current prognosticating groundhogs was compiled through a comprehensive internet search. In total, $n = 45$ groundhogs from Canada and the United States were identified. Of these 45 groundhogs, the final list was pruned to $n = 33$ groundhogs (Table 1) because our criteria were 1) the animal was a true groundhog (*M. monax*) and not another member of the Sciuridae family; 2) the animal was a living, breathing groundhog and not a taxidermized groundhog or stuffed puppet; and 3) that predictions were made by a reported visual inspection of a shadow and not by the groundhog ''whispering'' its prediction to a handler or choosing between labeled food bowls. For all remaining groundhogs in our analysis, annual predictions of ''early'' or ''late'' spring for a given groundhog were allegedly recorded by handlers as the presence or absence of a shadow when the groundhog exited its burrow. These records were accessed from publicly available news reports, fan page sites, conservation authorities, email contact with persons running twitter accounts for various groundhogs, and government agencies.

c. *Method for determination of early and late spring*

Climate records corresponding to each groundhog under evaluation were accessed using the nearest nationally catalogued weather station to the city, town, or village hosting a particular groundhog. Mean daily temperatures [(maximum temperature + minimum temperature)/2] were obtained and used to estimate GDD_0. A minimum of 30 years of climate data were acquired for each groundhog location to ensure a robust calculation of mean date of spring onset; only weather stations with nearly continuous data coverage were chosen, but where necessary multiple weather stations within the same county were used to create a full dataset (see Table A1 in the appendix). Climate data were accessed for Canada and the United States from Environment and Climate Change Canada (ECCC; https://climate-change.canada.ca/climate-data) and the NOAA (https://www.ncdc.noaa.gov/cdo-web) weather repositories, respectively.

Early and late are the only options a forecasting groundhog has at its disposal, so an objective determination of the onset of spring for each groundhog location was required. As North American groundhogs involved in spring predictions span a gradient of 16° of latitude, it was also important that our assessment of spring captured local discrepancies in spring phenology that are based on latitudinal clines. At each groundhog location, the estimated Carolina spring beauty bloom date was calculated (as the nearest day when accumulated GDD_0 surpassed 129 degree-days with starting date of 1 January of each year) and was assigned as the onset of spring for each year that a groundhog prediction was made. We then averaged these estimated Carolina spring beauty bloom dates across years to provide a mean onset of spring for each groundhog location. A locally objective early or late measure of spring for each groundhog-year prediction was determined if the estimated onset of spring (based on the estimated Carolina spring beauty bloom date from that year's GDD_0 estimate) occurred before or after this locally specific, time-averaged value. Because the estimated spring bloom date in a given year and location was reported as an integer-based yearday and average estimated bloom date for that location was left as a numeric value, we did not have any cases in which spring estimates ever fell on the estimated average date of spring.

To provide context for potential ''error'' in our estimated date of spring onset, given that the mean accumulated GDD_0 for the estimated bloom date of *C. caroliniana* includes error of ± 17°C days, this translates into a potential error around our estimated onset of spring of ±1 day at 17°C, which is a mean daily temperature that is not unusual to encounter during spring. However, because this onset date was subsequently turned into a bimodal variable (either early or late), given its distance relative to the mean onset over a minimum 30-yr record, this only introduces uncertainty in those dates within 1 day of the mean spring onset, representing very few (9%) of our observations, and is therefore unlikely to influence our results or conclusions.

d. *Data analysis*

Each location- and year-specific groundhog prediction was compared with our locally objective binary early or late spring estimate (described above). If a groundhog saw its shadow (predicting a late spring) and spring onset of that year was estimated to occur after the mean spring date for that location (observed late spring, based on the estimated bloom dates of Carolina spring beauty), then that groundhog made a successful prediction. Similarly, if the groundhog failed to see its shadow (predicting an early spring), but spring onset occurred after the mean date for that location (late spring), it would be an incorrect prediction. Similarly, all other possible combinations of groundhog predictions with our objective measure of spring onset were considered to make these determinations.

Logistic regression models were fit to each set of groundhog prediction and spring-onset data to determine the ability of groundhogs to successfully predict the onset of spring. To evaluate whether groundhog guesses collectively were any better than random chance, data from all 33 groundhogs were included in a single logistic regression to evaluate the rate of successful predictions across all groundhog locations. Logistic regression models were also run for each individual groundhog, although predictive power for certain models was low because of low sample sizes.

Additional analyses were performed to understand whether regional or landscape factors influenced the success of spring groundhog predictions. We examined the degree to which the latitude at which groundhogs resided might explain prediction success, and to settle a long-standing debate among the authors that emerged after a long afternoon and evening at the campus pub, a Welch's two-sample t test was conducted to evaluate the predictive success between Canadian and American groundhogs. Significance in all analyses was assessed at $\alpha = 0.05$.

With the notoriety, abundance of guesses, and national pride attached to predictions made by Punxsutawney Phil (Team USA; $n = 107$) and Wiarton Willie (Team Canada; $n = 54$), we performed an additional comparison for the predictions of these hogs alone. A chi-square test was conducted to evaluate the accuracy of these two hogs predicting the onset of spring. Significance was again assessed as $\alpha = 0.05$. In addition, data from these groundhogs (being the longest datasets) were used to determine whether groundhog predictions of late springs were increasing in frequency over time (which might be expected under global climate warming).

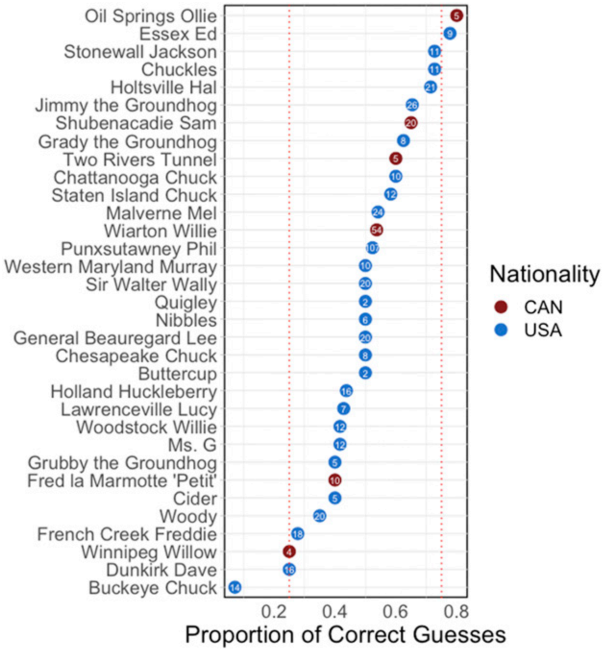

FIG. 2. Proportion of correct guesses for each groundhog; Canadian groundhogs are shown in red, and American groundhogs are shown in blue. Data points outside the vertical red dotted lines indicate groundhogs that were reasonably good at predicting the correct timing of spring (>0.75) or reasonably good at predicting the opposite of spring onset (<0.25). The number of observations for which a groundhog offered a prediction of spring are shown within each data point.

3. Results and discussion

Using a novel method of assessing the onset of spring across all regions reporting groundhog predictions, our analyses revealed that the likelihood of North American groundhogs correctly predicting the arrival of spring was quite literally no better than a coin toss. Using data among all 33 prognosticating groundhogs, there was no significant relationship between groundhog prediction and the estimated actual onset of spring (logistic regression; $P = 0.28$), and the overall percentage of correct guesses was 50% ($n = 530$ across all groundhog location/years). Considering individual groundhogs, not a single groundhog we evaluated had a significant relationship between their predictions and the estimated true onset of spring (logistic regression; P value range = 0.061–1 across all 33 groundhogs).

Both from their relative aptitude—or consistent ineptitude—in predicting the onset of spring, certain groundhogs appeared to be better at portending the coming spring season than others. Essex Ed (Essex, Connecticut), Stonewall Jackson (Wantage, New Jersey), and Chuckles (Manchester, Connecticut) all had greater than a 70% success rate of correctly predicting spring onset (groups with $n > 9$ observations; Fig. 2). By contrast, Buckeye Chuck (Marion, Ohio), Dunkirk Dave (Dunkirk, New York), and Holland Huckleberry (Holland, Ohio) had similar precision to this first group, but with opposite accuracy, demonstrating correct guesses across all three groundhogs less than 30% of the time (Fig. 2); in other words, it is better to bet against this latter group of groundhogs than with them.

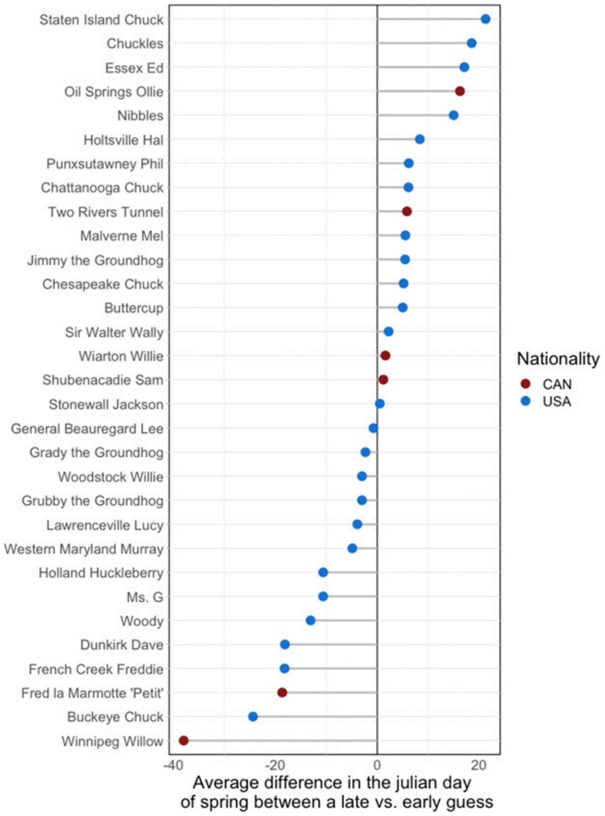

FIG. 3. The difference between mean observed spring dates for early and late predictions of each groundhog; positive values indicate a closer match between spring onset and groundhog predictions (i.e., spring occurs later on average when they predict late spring as compared with when they predict early spring), negative values indicate an opposite groundhog prediction to observed spring onset (i.e., spring occurs *earlier* on average when they predict late spring as compared with when they predict early spring), and values at or near zero represent no difference in spring onset between early and late groundhog predictions. Only groundhogs that have prognosticated at least twice were included in the figure.

Whereas the group of Essex Ed, Stonewall Jackson, and Chuckles may represent a farmer's best bet for knowing the onset of spring, their guesses should not be weighted equally. When observing the mean difference in yeardays between predictions of a late versus early spring, the guesses by both Essex Ed and Chuckles were categorically precise, with the onset of spring in a late prediction year arriving at least 17 days after the average estimated onset of spring in an early predicted year for their respective locations (Fig. 3). However, Stonewall Jackson was a good example of being lucky rather than accurate; despite having predicted spring successfully 73% of the time (Fig. 2), the difference in observed spring onset between his predictions of early and late springs was only a razor thin margin of 0.5 yeardays (Fig. 3).On the far end of the spectrum, it appears best to bet heavily against Winnipeg Willow's predictions; while Willow prognosticated

TABLE A1. Comprehensive list of weather stations used for estimating bloom date of Carolina spring beauty across groundhog locations. For each groundhog location, a minimum of 30 years of climate data were accessed. As a result of noncontinuous data collection for certain weather stations, there can be years for which multiple weather stations within the same county were used to calculate accumulated growing degree-days above 0°C (GDD_0).

Groundhog name	Weather station identifier	State/province	Country	Min year	Max year
Buttercup	USC00110442	Illinois	United States	2013	2020
Buttercup	USC00112736	Illinois	United States	1990	2013
Buckeye Chuck	USC00334942	Ohio	United States	1990	2006
Buckeye Chuck	USW00004855	Ohio	United States	2006	2020
Chattanooga Chuck	USW00013882	Tennessee	United States	1990	2020
Chesapeake Chuck	GHCND:USW00093741	Virginia	United States	2010	2010
Chesapeake Chuck	USC00443713	Virginia	United States	2007	2010
Chesapeake Chuck	USW00013702	Virginia	United States	1990	2007
Chesapeake Chuck	USW00093741	Virginia	United States	2011	2020
Cider	USC00060973	Connecticut	United States	1995	1999
Cider	USW00014740	Connecticut	United States	1995	1995
Cider	USW00014752	Connecticut	United States	1990	2020
Chuckles	USW00014740	Connecticut	United States	2009	2020
Chuckles	USW00014752	Connecticut	United States	1990	2008
Dunkirk Dave	USC00302197	New York	United States	2009	2020
Dunkirk Dave	USC00303033	New York	United States	1990	2012
Essex Ed	USW00014734	New Jersey	United States	1990	2020
French Creek Freddie	USC00461220	West Virginia	United States	1990	2002
French Creek Freddie	USW00003802	West Virginia	United States	2002	2020
Fred la Marmotte "Petit"	7051050	Quebec	Canada	1992	2019
Fred la Marmotte "Petit"	7058590	Quebec	Canada	1989	1992
General Beauregard Lee	USC00095874	Georgia	United States	1990	2013
General Beauregard Lee	USR0000GATH	Georgia	United States	2014	2020
Gordy the Groundhog	USW00014839	Wisconsin	United States	1990	2020
Grubby the Groundhog	USC00121747	Indiana	United States	1990	2014
Grubby the Groundhog	USW00053866	Indiana	United States	2014	2020
Grady the Groundhog	USC00313150	North Carolina	United States	1990	2004
Grady the Groundhog	USR0000NRUT	North Carolina	United States	2004	2020
Holland Huckleberry	USC00338366	Ohio	United States	1990	2000
Holland Huckleberry	USW00094830	Ohio	United States	2000	2020
Holtsville Hal	USW00004781	New York	United States	1996	2020
Holtsville Hal	USW00014734	New York	United States	1990	1996
Jimmy the Groundhog	USC00470308	Wisconsin	United States	1990	2020
Lawrenceville Lucy	USC00361838	Pennsylvania	United States	1993	2020
Lawrenceville Lucy	USC00368868	Pennsylvania	United States	1991	1993
Lawrenceville Lucy	USC00369408	Pennsylvania	United States	1990	2013
Malverne Mel	USC00305377	New York	United States	1990	1996
Malverne Mel	USW00094789	New York	United States	1996	2020
Ms. G	USC00196783	Massachusetts	United States	1990	2007
Ms. G	USW00014702	Massachusetts	United States	2007	2020
Nibbles	USW00013872	North Carolina	United States	1989	2019
Oil Springs Ollie	6127514	Ontario	Canada	1990	2006
Oil Springs Ollie	6127519	Ontario	Canada	2006	2020
Punxsutawney Phil	USC00367477	Pennsylvania	United States	1913	2020
Punxsutawney Phil	USC00367762	Pennsylvania	United States	1896	1910
Quigley	USW00004781	New York	United States	1990	2017
Quigley	USW00054790	New York	United States	2017	2020
Shubenacadie Sam	8202250	Nova Scotia	Canada	1990	2012
Shubenacadie Sam	8202251	Nova Scotia	Canada	2013	2020
Staten Island Chuck	USW00014734	New York	United States	1991	2020
Stonewall Jackson	USC00286177	New Jersey	United States	1990	1991
Stonewall Jackson	USC00288648	New Jersey	United States	1992	2001
Stonewall Jackson	USW00054793	New Jersey	United States	2001	2020
Sweet Pea	USC00448022	Newport News	United States	1990	2018
Sweet Pea	USW00093741	Newport News	United States	2019	2020

TABLE A1. (*Continued*)

Groundhog name	Weather station identifier	State/province	Country	Min year	Max year
Sir Walter Wally	USC00317079	North Carolina	United States	2000	2020
Sir Walter Wally	USW00013722	North Carolina	United States	1990	1999
Two Rivers Tunnel	8205700	Nova Scotia	Canada	1990	2014
Two Rivers Tunnel	8205701	Nova Scotia	Canada	2014	2020
Woodstock Willie	USC00111550	Woodstock	United States	2008	2020
Woodstock Willie	USC00473058	Woodstock	United States	1990	2008
Western Maryland Murray	USC00182282	Maryland	United States	2007	2020
Western Maryland Murray	USW00004781	Maryland	United States	1990	2007
Wiarton Willie	6119499	Ontario	Canada	2015	2020
Wiarton Willie	6119500	Ontario	Canada	1955	2014
Winnipeg Willow	5023222	Manitoba	Canada	1990	2000
Winnipeg Willow	5023262	Manitoba	Canada	2000	2020
Woody	USC00205452	Michigan	United States	1990	2002
Woody	USW00094889	Michigan	United States	2002	2020
Yonah the Groundhog	USC00092006	Georgia	United States	2020	2020
Yonah the Groundhog	USC00094230	Georgia	United States	1990	2020
Yonah the Groundhog	USC00097827	Georgia	United States	1999	2000

only 4 times, she was correct just 25% of the time, and on her prediction of a late spring, it actually arrived a full 38 days earlier than the mean onset of spring in the region. It is unfortunately clear that even if certain groundhogs can occasionally predict the onset of spring better than others, there appears to be no clear prophet among the group evaluated here.

Two groundhogs in particular have received national fame in their respective countries but are equally poor at predicting spring. Punxsutawney Phil from Pennsylvania, whose record spans over 100 years and who is the only groundhog to have been objectively studied to date, only predicted at a 52% success rate according to our evaluation criteria (chi-square test; $\chi_1^2 = 1.37 \times 10^{-31}$, with $P = 1$). By comparison, Wiarton Willie, the most famed groundhog from Ontario, Canada, performed no better, having predicted at a similarly dismal success rate of 54% (chi-square test; $\chi_1^2 = 0.11$, with $P = 0.74$). Our experimental estimate of success for Punxsutawney Phil splits the difference made by other formal evaluations; predictive success of our phenology-based estimates was lower than the 70% success rate reported by Aaron et al. (2001), which used a different metric for evaluation of spring onset and was slightly higher than the 40% success rate reported by NOAA (2020), although the methods of estimating spring onset in the latter reference are not reported. Comparisons between our phenologically derived estimate of success for Punxsutawney Phil and that of Aaron et al. (2001) should be made with caution; snow and temperature averages do not adequately address local and interannual variation, whereas GDD-based phenological estimates more effectively reflect the leafing, flowering, and fruiting of plants that coincide with the arrival and advancement of spring (Menzel et al. 2006).

Our analyses also indicated that any hope for geographic or national groundhog pride was unsupported. The proportion of correct spring predictions was not affected by the latitude where a groundhog forecast from (linear regression; $F_{1,30} = 0.13$, $R^2 = 0.002$, and $P = 0.72$), and although the density of guessing groundhogs is much higher in the United States than Canada, there was no difference in the overall (in)ability of Canadian or American groundhogs to correctly predict spring (Welch's two-sample t test; $t = 0.20$; degrees of freedom df = 5, 24; $P = 0.85$).

It appears that Punxsutawney Phil has a firm understanding of the warming world in which we now find ourselves. In the later part of his >100-yr climate record, Punxsutawney Phil has been predicting early springs (not seeing his shadow) with higher frequency (chi-square test; $\chi_1^2 = 12.7$, with $P = 0.0004$), which could be viewed as tracking global climate trends (Pachauri et al. 2014). Despite his earnest climate efforts, though, Punxsutawney Phil has yet to prove himself a successful forecaster on a year-to-year basis (Fig. 2). Unfortunately for Canada, they are still in search of their climate hero. Wiarton Willie, the only other groundhog with a substantial climate record (i.e., >50 yr) showed no propensity for predicting early versus late springs over his prognostication record (chi-square test; $\chi_1^2 = 1.18$, with $P = 0.28$).

The dearth of groundhogs' predictive ability with regard to the onset of spring reported in our study may not solely rest on the haunches of the groundhogs themselves. With the exception of the experience of fictional character Phil Connors (Ramis 1993), Groundhog Day is celebrated annually on 2 February; however, in North America groundhogs typically emerge from their burrows during March at the earliest (Zervanos et al. 2010). Perhaps if the holiday was shifted closer to March to better coincide with the typical emergence date for this species, these groundhogs might have a larger number of natural environmental cues to inform their predictions and improve their accuracy (although potentially reducing the usefulness of predictions, given the reduced timeframe between the date of prediction and actual spring onset). In addition, much of the available data with regard to groundhog predictions is based on relatively few observations (94% of our groundhogs had $n < 30$ predictions). As such, a repeat of our study in 50 years might provide a more robust dataset for analysis. One last drawback to our analysis and potential future endeavors in evaluating groundhog predictions is that the average groundhog life span in captivity is 14 years (Patrick et al. 2016). Unfortunately, few organizations report the ''replacement'' dates of particular groundhogs when their predecessors die. As such, predictive capacities of groundhogs could potentially vary individually within a given location, but such information is currently not available.

Through the most comprehensive and biologically relevant assessment of groundhog predictive capacity to date, and with the use of a novel and arguably more accurate assessment of the onset of spring than has been used in previous studies, it seems clear that groundhog predictions are entirely unrelated to the onset of spring. While these activities provide good reason to celebrate the anticipation of spring's arrival and a glimpse of hope for things to come from the doldrums of winter as February arrives each year, it is clear from our analysis that the predictions provided by these groundhogs are unlikely to replace the efforts of human meteorologists.

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Data availability statement. All data are available in the public domain; however, the authors are happy to share the dataset that supports the analyses presented here upon request.

APPENDIX

Comprehensive List of Weather Stations

Table A1 provides a list of the full weather station identification codes that were used for estimating bloom date of Carolina spring beauty for all of our groundhog locations, along with the year range of data that were accessed.

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