Report

Current Biology

Permanent daylight saving time would reduce deer-vehicle collisions

Highlights

- Deer-vehicle collisions are 14 times more likely shortly after dark than before
- Nighttime traffic and deer-vehicle collisions are more frequent during standard time
- Collisions with deer increase by 16% in the week following the autumn clock change
- Year-round daylight saving would reduce collisions, saving ~$1.2 billion annually

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In brief

The shift to standard time each autumn causes an abrupt increase in nighttime driving during the peak breeding season for deer, resulting in a 16% increase in deer-vehicle collisions. Cunningham et al. show that permanent daylight saving time would prevent 36,550 DVCs and $1.2 billion in collision costs annually in the US.

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Permanent daylight saving time would reduce deer-vehicle collisions

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SUMMARY

Overlap between wildlife and human activity is key to causing wildlife-vehicle collisions, a globally pervasive and growing source of wildlife mortality.[1,2] Policies regarding clock time often involve abrupt seasonal shifts in human activity, potentially influencing rates of human-wildlife conflict. Here, we harness the biannual shift between standard and daylight saving time as a natural experiment to reveal how the timing of human activity influences deer-vehicle collisions. Based on 1,012,465 deer-vehicle collisions and 96 million hourly traffic observations across the United States, we show that collisions are 14 times more frequent 2 hours after sunset than before sunset, highlighting the importance of traffic during dark hours as a key determinant of deer-vehicle collision risk. The switch from daylight saving to standard time in autumn causes peak traffic volumes to shift from before sunset to after sunset, leading to a 16% spike in deer-vehicle collisions. By reducing traffic after dark, our model predicts that year-round daylight saving time would prevent 36,550 deer (*Odocoileus* sp.) deaths, 33 human deaths, 2,054 human injuries, and US$1.19 billion in collision costs annually. In contrast, permanent standard time is predicted to increase collisions by an even larger magnitude, incurring an additional US$2.39 billion in costs. By targeting the temporal dimension of wildlife-vehicle collisions, strategies such as year-round daylight saving time that reduce traffic during dark hours, especially during the breeding season of abundant ungulates, would yield substantial benefits for wildlife conservation and reduce the social and economic costs of deer-vehicle collisions.

RESULTS

Patterns of deer-vehicle collisions

Vehicular strikes are a dominant cause of death for many wildlife species.[1,2] Around 2.1 million deer-vehicle collisions occur in the US annually, causing more than $10 billion in economic losses,[3] 59,000 human injuries, and 440 human deaths.[4] We compiled a dataset of 1,012,465 deer-vehicle collisions (DVCs) with hourly temporal precision across 23 states of the US from 1994–2021. On average, DVCs comprised 6.5% of total vehicle collisions, with 0.97 in 1,000 reported DVCs leading to human deaths (Table S1).

DVCs showed a strong seasonal pattern, spiking in late October through November in all states analyzed except Alaska (Figures 1A and 1C; Figure S1). Almost 10% of DVCs occurred during the 2-week period centered on the autumn clock change, which is 2.5 times greater than expected if collisions were uniformly distributed (Figure 1C). The strong peak in DVCs in autumn coincides with both the switch from daylight saving time (DST) to standard time as well as the deer breeding season, known as the "rut." During the rut, ungulates (especially males) increase movement rates by up to 50%,[5,6] increasing their vulnerability to vehicle collisions.[7] The rut for white-tailed deer typically lasts only 2 to 3 weeks, beginning in late October or early November,[8] whereas the timing of the rut can be more heterogeneous for mule deer, *O. hemionus*.[9] Consistent with these patterns, collisions were more concentrated in autumn in eastern states (skewness = 1.94) where only white-tailed deer are present as compared to western states (skewness = 0.19) where mule deer predominate (Figures 1C and S1).[10] Species-specific differences in the timing of the rut thus amplify the effect of the autumn clock change in eastern states where highly abundant white-tailed deer cause exceptionally high DVC rates to begin with,[11] highlighting the importance of seasonal changes in wildlife activity for predicting collision risk.

Daylight saving time reduces traffic at night and deer-vehicle collisions

DST, the practice of advancing clocks by 1 hour during the warmer months, is observed by a quarter of the world's population.[12] By shifting the timing of human activity relative to sunlight, DST results in later sunrises and sunsets relative to clock time. The biannual change between time systems causes an abrupt shift in the timing of human activity relative to sunrise and sunset (i.e., solar time). Because most species of wildlife have distinct diel patterns of activity based on solar time (e.g., diurnal,

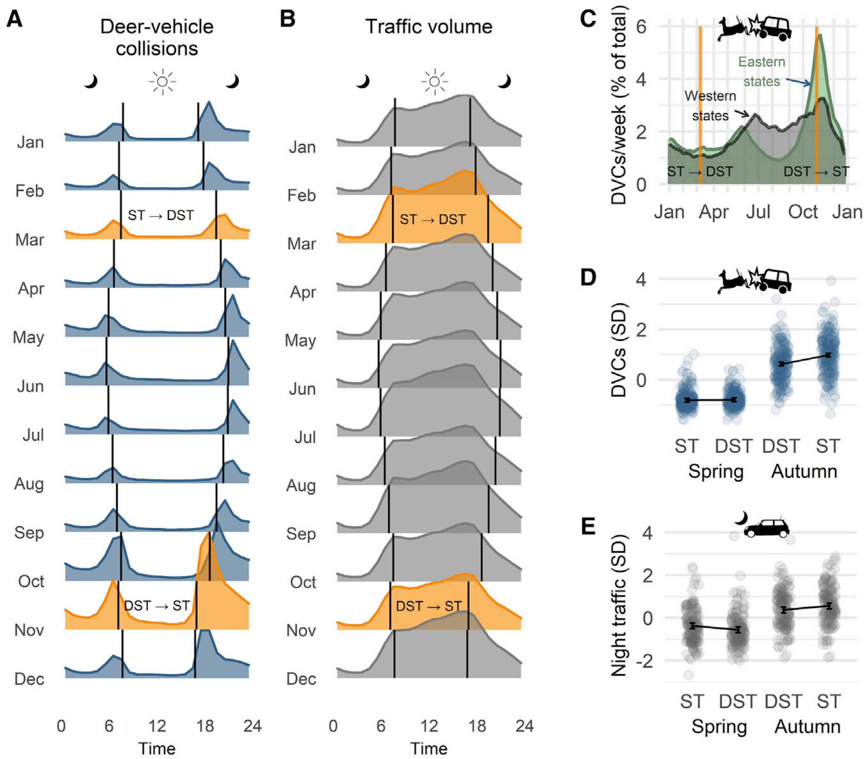

Figure 1. Changes in deer-vehicle collisions throughout the year

(A) DVCs are tightly clustered in the hours before sunrise and after sunset (vertical lines), with peaks in collisions tracking seasonal changes in day length. These density distributions (y axes standardized across months) were derived from 1,012,465 deer-vehicle collisions from 23 states of the US (raw data).

(B) In contrast, the timing of vehicle traffic shows little change over the course of the year, such that shifting clocks forward in November increases the amount of low-light traffic. These density distributions (y axes standardized across months) were characterized using the raw aggregated data for the 23 states based on 96 million hourly observations of traffic volumes between 2013 and 2019.

(C) In the states in our sample east of Wyoming (green) where white-tailed deer predominate, deer-vehicle collisions have a tight peak in November during the 2 to 3 week breeding season, coinciding with the time switch (orange lines). In western states (grey) where mule deer predominate, deer vehicle collisions are more spread out across summer and autumn. Graphs are based on raw data.

(D) Collisions increased by an average of 16% in the week following the autumn switch, while there was no change following the switch from standard time to DST in the spring.

(E) Low-light traffic volumes are higher under standard time.

In (D) and (E), error bars show the model-estimated 95% confidence interval from the linear mixed-effects models, and the data points correspond to the number of collisions or low-light traffic volumes observed in the 7-day period before or after the time switch for each combination of year and state. Data were scaled for each state separately by centering and dividing by the standard deviation (SD), thereby placing the data from all states on a common scale.

See also Figure S1 for state-by-state graphs of the raw DVC data and traffic volumes and Table S2 for model selection tables.

nocturnal, and crepuscular patterns[13,14]), changes in the timing of human activity have the potential to either increase or decrease human-wildlife conflicts such as collisions.

DVCs were tightly clustered in the hours before sunrise and after sunset in all states, with 76% occurring at night. The timing of collisions closely tracked seasonal and latitudinal changes in daylight (Figures 1A and S1). In contrast, the timing of vehicle traffic showed no substantial change over the course of a year, indicating that clock time rather than solar time is the major determinant of traffic volume (Figures 1B and S2). The shift from DST to standard time in November led to a sudden increase in low-light traffic (between sunset and sunrise), with peak traffic volume (∼4:30 p.m.) shifting from before sunset in October to coinciding with sunset in November, on average (Figure 1B). If clocks remained on DST, peak traffic volume would instead occur before sunset for the duration of winter in most of the US.

We used linear mixed-effects models to compare low-light traffic volumes and DVC rates between the weeklong periods immediately before and after the time changes in spring (second Sunday of March) and autumn (first Sunday of November). In both seasons, low-light traffic volume was 6%–8% higher under standard time than DST (Figure 1E; Table S2). DVCs increased by 16% in the week following the switch from DST to standard time in autumn, but surprisingly, DVC rates were unaffected by the switch from standard time to DST in spring (Figure 1D; marginal R^2 = 0.78; Table S2). The autumn time switch likely has a larger effect because it occurs during the deer breeding season, when deer are most active and vulnerable to vehicle collisions.[7]

The effect of position in time zone

Relative position in a time zone causes differences in the relationship between human activity and solar time,[15,16] with sunrise and sunset occurring at earlier clock times in the eastern region of a time zone. Annual collision rates at the county level were associated with relative position in a time zone (Table S3). After controlling for baseline correlates of DVC rates (human population, primary productivity, and urban land cover[17–19]), counties at northern latitudes, where day lengths are shorter in winter, had an average of 1.86 times more collisions than counties at more southerly latitudes (Figure 2). Likewise, counties in the eastern portion of a time zone, where sunset occurs earlier than in the west, had an average of 1.35 times more collisions than counties at the western margins of a time zone (Figure 2). The larger effect size of latitude is consistent with the hypothesized mechanism of low-light driving: latitudinal shifts cause an absolute difference in daylight hours, whereas relative longitude only influences the relationship of sunlight to clock time, so changes in post-sunset driving could be partly offset by changes in pre-sunrise driving.

Hourly collisions over the year

Using a generalized additive model (GAM), we modeled the hourly number of DVCs over the course of the year as a function

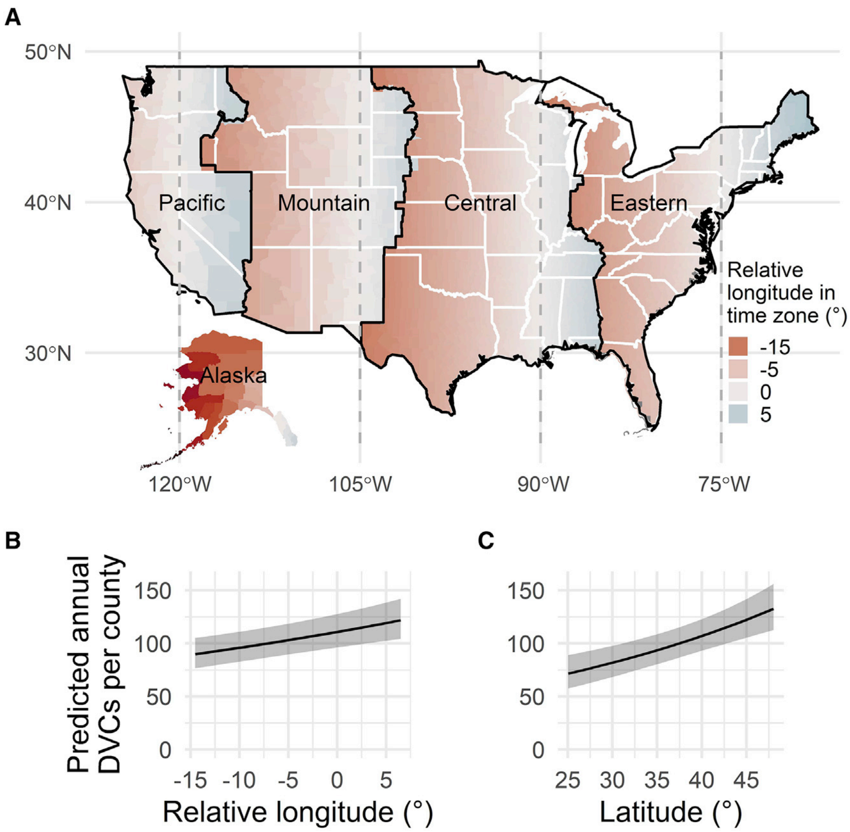

Figure 2. The association between deer-vehicle collisions and a county's relative position in a time zone

(A) Colors show a county's relative longitude within a time zone. Relative longitude is measured in degrees from the solar central meridian of a time zone (dashed vertical lines), corresponding to the approximate longitude at which the sun is at its highest at midday.

(B and C) After controlling for other correlates of deer-vehicle collisions, the generalized additive model indicates that the annual number of collisions (± 95% CI) in a county is on average higher in counties in the east of a time zone and in counties at higher latitudes.

See also Table S3 for model selection table.

of an interaction between traffic volume and time of day (relative to sunrise and sunset). This model explained 93.7% of the deviance and revealed a strong interactive effect between traffic volume and the time of day (differing by state; Table S4): higher traffic volume increased the number of DVCs but only during dark hours (Figure S2). Although deer are equally active during the hours around dawn and dusk,[6,20,21] our analysis shows they are far more vulnerable to collisions when it is dark. Holding traffic volume at its mean, our model predicts that collisions are 14 times more frequent 2 hours after sunset than 2 hours before sunset (averaged across states; Figure 3B). DVCs were also biased toward the evenings, occurring 2.3 times more often in the 2 hours after sunset than the 2 hours before sunrise (Figure 4C), which our model indicates occurs because traffic volumes are higher in the evening (Figures 1B and S2).

Quantifying the societal consequences of different time systems

There is growing recognition that the biannual time switch carries societal costs. Most surveyed Europeans (86%) and Americans (71%) are in favor of "locking the clock," but there is not yet consensus on whether standard time or DST is preferred.[22,23] The European Parliament recently voted to abolish the time shift but has not yet agreed on which time system to use,[24] and the US Congress is currently considering instating year-round DST.[25] To quantify the consequences of alternative time policies for conservation and society, we constructed counterfactual scenarios for permanent DST and permanent standard time by shifting the timing of sunrise and sunset and using our generalized additive model to predict the hourly number of DVCs that would have occurred.

These scenarios indicate that permanent DST would cause the annual number of DVCs to decline by an average of 2.3% across states, ranging from an increase of 2.5% in Kansas to a decrease of 8.3% in Maine (Figures 4A and 4D; Table S5). States in the far east of a time zone were predicted to experience larger reductions in DVCs under permanent DST than states in the far west of a time zone (Figure 4G; Table S3). In contrast to widespread reductions under DST, permanent standard time is projected to increase DVCs in all states (Figures 4B and 4D), ranging from 1.08% in Florida to 15.6% in Utah (mean = 5.2% increase), and there were no consistent effects of a state's position in time zone (Table S3). The greater magnitude of change under standard time occurs because the hypothetical time shift would apply over ~8 months compared to 4 months under permanent DST.

Scaling these estimates up to the total number of DVCs expected in each state (Table S5), while propagating uncertainty and accounting for un-surveyed states, our model predicts that permanent DST would reduce DVCs by 36,550 (95% confidence interval [CI]: 33,877–39,299) annually in the US. This reduction would prevent an estimated 2,054 human injuries, 33 human deaths, and US$1.19 billion in damages annually (based on an average DVC cost of $32,472; Table S5). In contrast, our model predicts that permanent standard time would increase the number of DVCs by 73,660 (95% CI: 70,346–77,104) annually, incurring a further US$2.39 billion in collision costs, 4,140 human injuries, and 66 human deaths.

DISCUSSION

Conservation ecology has overwhelmingly focused on mitigation measures that address the spatial causes of collision risk.[26–29] By addressing the temporal rather than spatial dimension of deer-vehicle collisions,[7,30] our study directly shows that the timing of traffic is a dominant determinant of deer-vehicle collisions, with high traffic volumes increasing collision risk only

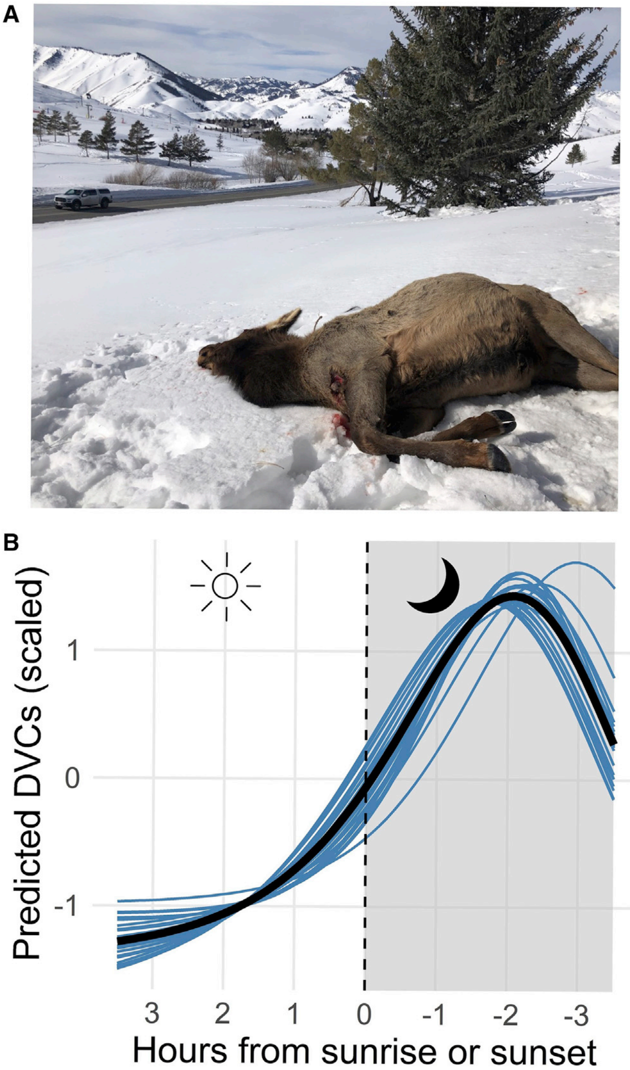

Figure 3. Deer-vehicle collisions increase at night

(A) Vehicular collisions with ungulates like deer, moose, and elk (pictured) are highly consequential for both wildlife and humans, killing >2 million ungulates and causing >$10 billion in economic losses in the US annually. Photo: Taylor Ganz.

(B) Holding traffic volume constant (at each state's mean), the generalized additive model shows that deer-vehicle collisions increase substantially during dark hours. Averaged across states (black line), collisions were 14 times more frequent 2 hours after sunset compared to 2 hours before sunset. Blue lines show the predictions for each of the 23 states in our sample. To place all states on a common scale for visualization purposes, model predictions were scaled by centering and dividing by the standard deviation.

See also Figure S2 for graphs of state-by-state effects and Table S4 for summary of GAM parameters.

during hours of darkness. This finding may explain why results from prior studies have sometimes conflicted regarding the role and importance of traffic volume in determining collision rates.[29] Mitigation strategies that place greater emphasis on the temporal dimension of collision risk would likely have widespread benefits with minimal direct costs. Year-round DST presents one such way of reducing traffic volumes at night,[31] with our analysis indicating DST reduces collisions simply by shifting the times at which humans are active relative to sunlight. In contrast, year-round standard time would incur significant animal mortality and societal costs, estimated here at 66 human fatalities and more than $2 billion in the US annually.

Although deer are equally active in the hours either side of sunrise and sunset,[6,20,21] DVCs are far more likely to occur when it is dark. This pattern provides compelling evidence that the dominant cause of deer-vehicle collisions is the ability of drivers to see animals, which is substantially impaired by darkness. However, the seasonal spike in DVCs during the autumn breeding season indicates that seasonal changes in animal activity also play an important role, with risk likely peaking for species when their periods of greatest activity overlap with periods of frequent low-light driving. Most mammals and amphibians are crepuscular or nocturnal,[13,32] and nocturnality is accentuated near areas of human activity such as roadways.[33] Thus, reductions in low-light traffic volumes under permanent DST, or through other measures, would likely reduce collision-induced injuries and deaths of other nocturnal mammal and amphibian species. This knowledge could assist with developing seasonal or dynamic mitigation strategies, such as temporary reductions in nighttime speed limits coupled with strategies that promote compliance.[34] Importantly, strategies that target the temporal and spatial dimensions of collision risk are not mutually exclusive and should be deployed concurrently. In strategic locations, wildlife overpasses and underpasses can be cost effective and highly successful at reducing collisions,[26,27] while facilitating safe animal movements.[35] Natural solutions, like wolf[36] and cougar[11] recovery in the eastern US may also reduce DVCs by causing changes in both deer density and behavior.

While our calculations indicate that permanent DST would save nearly 37,000 deer lives per year and permanent standard time would lead to 74,000 additional deer deaths annually, these numbers are likely gross underestimates of the implications for wildlife. Our estimates of DVCs are based on insurance industry reports (Table S5), which are biased towards abundant large animals like deer because they cause the vast majority of vehicle damage.[3,27] We expect these estimates are a reasonable, albeit conservative, reflection of the number of DVCs that lead to substantial property damage and human injuries. Nevertheless, ~50% of DVCs are not reported to insurance companies,[37] so the number of deer lives saved by permanent DST and lost by permanent standard time could be twice as large as our estimate. We characterized traffic volumes only on two-lane roads, on which ~90% of reported DVCs occur (see page 38 of Huijser et al. [2008][3]). Roads with more than two lanes may have different temporal patterns of traffic that aren't captured in our models, but their relatively small contribution to overall DVCs (<10%) likely leaves our results robust to this simplification.

Both permanent daylight saving and standard time will carry costs and benefits. DST was first enacted to reduce energy consumption by shifting daylight towards the evening clock hours; this shift has also been shown to reduce crime, boost economic activity, and reduce overall collision rates and pedestrian fatalities.[38] Nevertheless, the US (1918 to 1919, 1942–1945, and 1974–1975[39]), Russia (2011–2014[40]), and the United Kingdom (1968–1972[41]) have trialed permanent DST, and each ceased after it was unpopular with the public.[15,39] The medical community

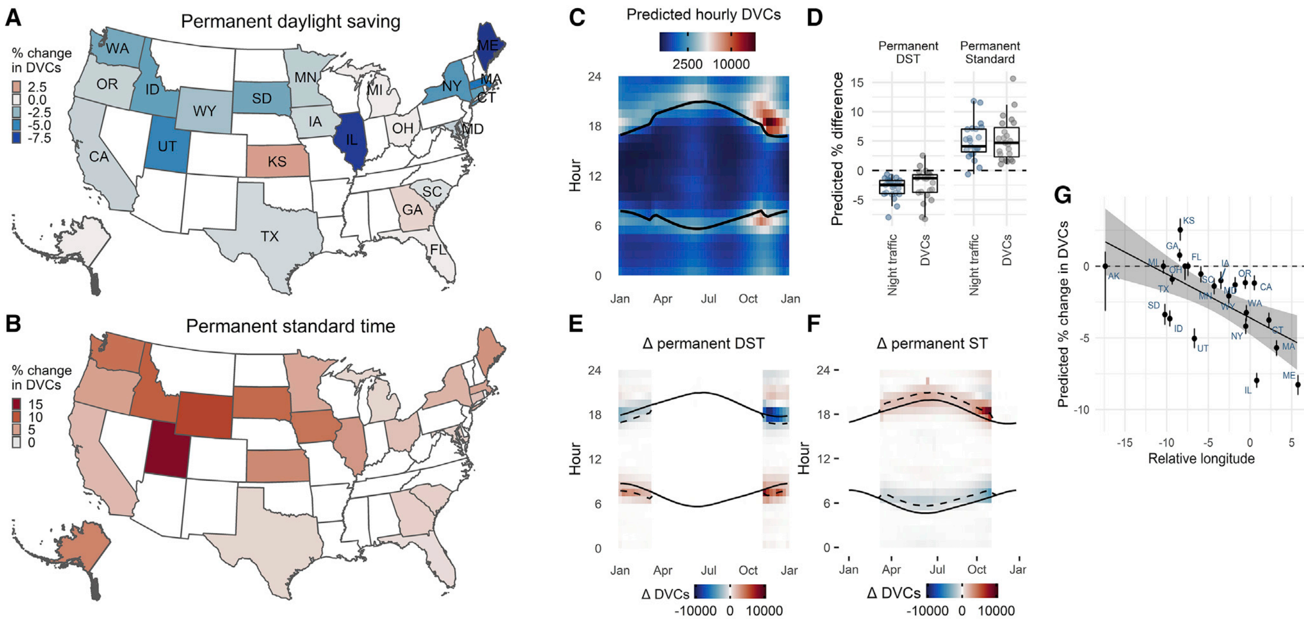

Figure 4. Permanent DST would reduce the number of deer-vehicle collisions in the US

(A and B) Maps show the GAM-estimated percentage change in deer-vehicle collisions (DVCs) in counterfactual scenarios where either daylight saving (A) or standard time (B) become permanent. States shown in white did not provide suitable data for this analysis.

(C) The pixels represent the model-estimated number of DVCs in each hour of each week, revealing that collisions are clustered in the hours after sunset and before sunrise, with a strong peak in November. The solid black line indicates average sunset and sunrise times under the status quo.

(D) The expected percentage change in DVCs and traffic volume between sunset and sunrise ("night traffic") under permanent DST or permanent standard time. The data points represent model estimates for each of the 23 states analyzed here.

(E and F) The model-estimated difference in the hourly number of collisions across the US under permanent DST (E) and permanent standard time (F), relative to the status quo (C). Solid black lines in (E) and (F) represent mean sunrise and sunset times under the respective scenario, with dashed lines denoting the status quo. Warm and cool colors show hours with predicted increases and decreases in DVCs, respectively.

(G) Relationship between a state's geographic position in a time zone and the GAM-predicted percentage change in DVCs under permanent DST. Data points show the GAM-estimated percentage change (± 95% confidence interval) for each state in our sample, and the line shows the fit (±95% CI) of the best-performing linear regression. Relative longitude measures the distance in degrees from the solar central longitude of a time zone, with negative values indicating west and positive values indicating east.

See also Figure S1 for state-by-state graphs of the raw DVC data, Table S3 for model selection table for the post-hoc analysis of geographic position, Table S4 for summary of GAM parameters, and Table S5 for model-estimated percentage change.

cautions that later exposure to sunlight under year-round DST could contribute to problems such as sleep deprivation,[12] depression,[40] cancer,[41] social jetlag,[15] cardiovascular conditions,[42] reduced longevity, and overall health.[43] It is further possible that cognitive fatigue may offset some of our model-estimated benefits of permanent DST. Despite these other considerations, our study adds a new argument in favor of permanent DST by demonstrating that shifts in the timing of human activity with respect to daylight reduces animal-vehicle collisions, a major source of human-wildlife conflict with substantial societal and ecological costs. Our findings support earlier studies that drew a link between standard time and increased collisions with white-tailed deer (*Odocoileus virginianus*) in New York[31] and koalas (*Phascolarctos cinereus*) in Queensland, Australia.[44] Most jurisdictions that observe seasonal time changes are located at latitudes greater than ~20° (north and south) and thus experience similar patterns of daylight as the US. In several of these regions (e.g., Canada and Europe), ungulate-vehicle collisions are also a major problem, with the predominant species in each region also breeding in autumn. Thus, it seems likely that a general trend of reduced DVCs under permanent DST may apply to other countries as well.[45] Based on our findings, we might expect year-round DST to cause greater reductions in DVCs in eastern regions of time zones (Figure 4G). Our results for Alaska (−1.28% DVCs, −4% night traffic; Table S5) indicate that even far northern latitudes, where changes in day length are extreme, may also experience reduced DVCs under permanent DST. Ultimately, selecting the time system or time zone boundaries that provide the largest benefit for society, as well as the environment, will require a nuanced and comprehensive cost-benefit analysis that incorporates all of the emerging evidence from diverse fields.

Our findings demonstrate the critical importance of considering the temporal dimensions of both human and animal behavior to identify mechanisms underlying rates of conflict such as animal-vehicle collisions. Our analyses reveal that, by shifting the timing of peak traffic relative to daylight, daylight saving policies substantially impact rates of anthropogenically caused wildlife mortality. As anthropogenic impacts continue to intensify globally,[46] it is crucial to identify opportunities to mitigate harmful effects on the natural world. The opportunity we identify here—adherence to permanent DST—would benefit wildlife conservation and reduce the social and economic costs of deer-vehicle collisions.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.cub.2022.10.007.

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AUTHOR CONTRIBUTIONS

T.A.N. and C.X.C. conceived of the idea for the paper. All authors contributed to data curation. C.X.C. conducted the formal analysis, created the figures, and wrote the first draft of the paper. All authors contributed to revision and editing. L.R.P. supervised the lab.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

We support inclusive, diverse, and equitable conduct of research.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Deer-vehicle collisions	This paper	Figshare: 10.6084/m9.figshare.21112903
Summarized hourly traffic volumes	This paper	Figshare: 10.6084/m9.figshare.21113005
Explanatory variables used in models	This paper	Figshare: 10.6084/m9.figshare.21112789
Software and algorithms		
Code used in these analyses	This paper	Figshare: 10.6084/m9.figshare.21112744
R, version 4.1.2	R Core Team[47]	https://www.r-project.org/
lme4, version 1.1-27.1	Bates et al.[48]	https://cran.r-project.org/web/packages/lme4/index.html
mgcv, version 1.8-40	Wood[49]	https://cran.r-project.org/web/packages/mgcv/index.html
suncalc, 0.5.0	Thieurmel and Elmarhraoui[50]	https://cran.r-project.org/web/packages/suncalc/index.html
Other		
Raw hourly traffic volumes	US Department of Transportation[51]	https://www.fhwa.dot.gov/policyinformation/tables/tmasdata/#y19
Human population size of counties	United States Census Bureau[52]	https://www.census.gov/data/datasets/time-series/demo/popest/2010s-counties-total.html
MODIS net primary productivity	Running and Zhao[53]	http://files.ntsg.umt.edu/data/NTSG_Products/MOD17/MODIS_250/modis-250-npp/
Urban and built-up land cover	Theobald et al.[54]	https://zenodo.org/record/3963013#.Yx-vxnbMK70

RESOURCE AVAILABILITY

Materials availability

This study did not generate new unique reagents.

Data and code availability

- Deer-vehicle collision data and summarized hourly traffic volumes have been deposited at Figshare. DOIs are listed in the key resources table.
- All original code has been deposited at Figshare and is publicly available as of the date of publication. DOIs are listed in the key resources table.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

METHOD DETAILS

Deer-vehicle collision and traffic data

Most US states collect data on vehicle collisions, including whether a collision involved an animal. We requested data from all states of the US (excluding Hawaii, where ungulate collisions are uncommon; Table S5) either by individually contacting a state's Department of Transportation, or through the Highway Safety Information System, which maintains a database for nine states. We retained the data from a given state if the information provided included the date, time, and whether the collision involved an animal. This left 23 states, totaling 1,012,465 animal-vehicle collisions. Because >90% of reported animal-vehicle collisions in the US are with deer,[3] we use "deer-vehicle collisions" (DVCs) when referring to this dataset. Sixteen states recorded the timing of the collision to the nearest minute, while the remaining seven states recorded the timing of collisions in one-hour bins.

We characterized patterns of hourly traffic volumes for each state. We did not intend for this to provide an absolute estimate of traffic volumes in a given location, but rather the typical hourly traffic patterns relative to other hours of the year. The US Federal Highway Administration collects traffic volumes at approximately 5,000 continuous traffic stations across the US. These stations record the count of vehicles per hour on a range of different road types.[51] We downloaded traffic volumes for all states of the US from 2013-2019, and then selected only the 23 states for which we had DVC data. Because ~90% of animal-vehicle collisions in the US occur on two-lane roads,[3] we retained traffic stations on two-lane roads only. Finally, we retained traffic stations if they recorded data for at least 300 days in a given year. Because the remaining dataset was large (98-million counts of hourly traffic volume), we summarized the data by calculating the mean hourly traffic volumes for each week of the year (1-52), averaged over the period 2013-2019. For each state, this resulted in 1248 (52 weeks × 24 hours) hourly estimates of mean traffic volume. Then, for each state separately, we scaled traffic volumes by centering and dividing by the standard deviation (Figure S1). This placed each state on a common scale, with positive values signifying hours with above average traffic, and negative values signifying hours with below average traffic volume (Figure S1).

QUANTIFICATION AND STATISTICAL ANALYSIS

The effects of switching clocks

We aimed to investigate relative changes in DVCs and low-light traffic volumes as a result of the bi-annual time-switch. For both DVCs and traffic volumes, we selected data from the seven days before and after the autumn and spring time switches, from which we calculated the number of DVCs and the volume of low-light traffic occurring in each seven-day period. We did this for each year in each state (i.e., if a state had ten years of data, we calculated ten counts of DVCs before and after each time switch). The number of DVCs reported differed substantially between the states, likely the result of real differences in DVCs but also artifacts arising from different reporting rules. Thus, for both datasets, we standardized the data separately for each state by centering and dividing by a state's mean, thereby placing the data from all states on a common scale. To test the sensitivity of the results to our use of seven-day periods, we additionally compared model results using 14-day periods, revealing consistent trends (not presented here).

We analyzed the effect of switching clocks using a linear mixed-effects model. For the model of DVCs, we used the scaled number of DVCs (Gaussian-distributed) in each seven-day period as the response variable. For the model of low-light traffic volume, we used the scaled traffic volume (Gaussian-distributed) in each seven-day period as the response variable. We fitted both models in response to an interaction between the season (spring or autumn) and the time system (DST or standard time). To account for the non-independence of repeated observations, all models included a random intercept structure of season nested within year nested within state. To account for state-by-state differences in the number of DVCs, we weighted each state by its proportional contribution to the total expected number of DVCs in the US, as estimated by the insurance industry (Table S5). This assigned a higher weight to states with more expected DVCs. Similarly, we weighted the model of scaled traffic volume according to the number of licensed drivers in a given state (Table S5). We selected the best-performing model by comparing all simpler combinations of explanatory variables using small-sample corrected Akaike information criterion (AICc). We fitted the models using the 'lme4' package v1.1-27.1[48] in R v4.1.2[47].

The effect of geographic position in time zone

We modelled the effect of a county's relative position in a time zone on its annual DVC rate. Relative position in a time zone influences the relationship between clock time and sun time, with sunrise/sunset occurring at earlier clock times in the east of a time zone. We calculated relative longitude in relation to the solar central meridian of a time zone, which we defined using increments of 15 degrees from the prime meridian in Greenwich, U.K. (as in[15,16]). Because the earth rotates 15 degrees every hour (360°/24 h), these increments correspond to the approximate longitude at which the sun is at its highest point at midday.[15,16] We did not include Alaska in this analysis of position in time zone due to very large county sizes and small human population sizes.

We first developed a baseline model to control for key broad-scale correlates of DVC rates, and then tested whether including the geographic position in a time zone further improved model fit. We expected that deer densities would be higher in counties with higher net primary productivity[17] and that larger human populations would correspond with more vehicle traffic, both of which are positively associated with collision rates.[19] We additionally expected that the proportion of urbanized land cover may be a useful measure of the extent of non-habitat.[18] Thus, using a generalized additive mixed-effects model (Gamma distribution), we modelled the annual collision rate of each county (DVCs divided by years of data) in response to (i) human population (log-transformed)[52]; (ii) total annual net primary productivity (log-transformed) of a county[53]; and (iii) the proportion of a county that was urbanized.[54] We included a random intercept for state in all models to account for potential state-by-state differences in reporting rules. Next, we sequentially tested whether adding linear effects of latitude and relative longitude improved model fit. We ranked models using AICc and visualized the marginal effects (i.e., excluding random effects) of the best-performing model across the observed ranges of the covariate of interest, while holding other covariates at their means.

Hourly collisions over the course of the year

We constructed a model of the hourly number of DVCs to quantify the strength of mechanisms that we expected would influence collision frequency: wildlife temporal activity, traffic volume, differences in driving difficulty between day and night, and seasonal changes in wildlife behavior. Ungulates are typically crepuscular,[6,20,21] and the two most abundant ungulate species in the US, white-tailed deer and mule deer, have relatively equal-sized bimodal activity peaks at sunrise and sunset.[6,20,21] Because the morning and evening peaks are usually similar in size,[6,20,21] the role of deer activity patterns alone should lead to equivalent collision risk at sunrise and sunset. Thus, to reflect animal activity patterns, we created a symmetrical explanatory variable measuring the minimum number of hours from each collision to sunrise or sunset ('*hrsSunriseSunset'*), with positive values reflecting daylight hours and negative values reflecting dark hours. For each collision, we calculated sunrise and sunset times at the centroid of the county in which the collision occurred using the 'getSunlightTimes' function of the 'suncalc' R package.[50] Collision coordinates or a county identifier was not provided for 1.1% of collisions, in which cases we calculated sunrise and sunset at the center of a given state, which inserts a small degree of noise (up to ∼20 min) if a collision actually occurred at the extremities of a state. To model the effect of human driving patterns, we used the scaled hourly '*traffic'* volumes (described earlier). Finally, to control for seasonal changes in deer behavior such as the rut,[7] we included a continuous explanatory variable for '*week'* of the year (1-52).

Traffic volumes and the timing of collisions (7/23 states) were recorded in one-hour bins. Thus, we aggregated all DVCs into one-hour bins (centered; e.g., 1-2am was reflected by 1:30am) for each week of the year in each state (Figure S1). We modelled the hourly number of collisions using a generalized additive mixed-effects model (GAMM), which allowed us to model smooth, non-linear effects of the explanatory variables, known as 'smooths'. The model took the form:

$$\text{DVC} \sim f(\text{traffic}, \text{hrsSunriseSunset}) + f(\text{traffic}, \text{hrsSunriseSunset})\text{state} + \text{state} + f(\text{week})\text{state}$$

where *DVC* is the number of animal-vehicle collisions in a given hour; *f(traffic, hrsSunriseSunset) is* a global effect of a tensor product interaction between hourly traffic volume and the hours from sunrise or sunset, while *f(traffic, hrsSunriseSunset)state* allows this interaction to differ for each state; *state* denotes a random intercept for each state; and *f(week)state* denotes a non-linear function of week of year, differing for each state. Because week of year is a circular variable (i.e., week 52 is next to week 1), we used a circular cubic regression spline, forcing the ends to meet up. We fitted the model using the negative binomial distribution to model overdispersion in the count data.[55] Using the 'bam' function of the 'mgcv' package,[49] we imposed a selection penalty on each smooth effect, such that a smooth effect would be penalized out of the model if it was not needed.[56] This represents a form of automatic model selection.[56]

Projecting to counterfactual scenarios

We constructed counterfactual scenarios in which either DST or standard time are made permanent. We did this by creating new datasets with the timing of sunrise and sunset shifted by one hour at the appropriate time of year, while holding traffic volumes unchanged. For permanent DST, this involved shifting the timing of sunrise and sunset one hour later during winter (weeks 45 through to 10). For permanent standard time, this involved shifting the timing of sunrise and sunset one hour earlier during the summer and surrounding months (weeks 11-44). These scenarios assume that traffic volumes are determined by clock time, not the timing of sunrise and sunset. This appears to be the case, with hourly traffic volumes showing little association with seasonal changes in day length (Figures 1B and S1).

We used the GAMM to predict the number of collisions (± standard error) occurring in each hour of the 52 weeks of a year. We did this for each state under the status quo and counterfactual scenarios. Because the DVC data are a sample of the total number of collisions, we needed to scale-up the model estimates in order to estimate the total number of DVCs. The insurance industry (State Farm) provides annual estimates of the total number of deer-vehicle collisions in each US state. We therefore calculated a scaling factor for each state, which when multiplied by the model-predictions under the status quo, scales them to equal the number of collisions expected by State Farm. Each state's scaling factor was calculated by summing the model-estimated number of collisions under the status quo, and then dividing by the number of collisions expected for that state.

We then evaluated differences in the model-estimated number of collisions between the status quo and the counterfactual scenarios. We propagated uncertainty in the model-estimated differences using a Monte Carlo error propagation routine. This routine yielded the expected percentage difference in collisions for each state (Figures 4A, 4B, and 4D). In addition to estimating differences among the states, we also estimated aggregated differences for the US under the different scenarios. The 23 states analyzed here contribute an estimated 54% of DVCs in the US (Table S5). Assuming the 23 states analyzed here are a representative sample of the US, we therefore scaled-up the estimates to account for the un-surveyed states by multiplying the estimates by a scaling factor of 1/0.54. We recognize that there are other sources of uncertainty that have not been propagated, like uncertainty in the insurance industry's estimates of the number of collisions in each state. Unfortunately, there were no estimates of uncertainty for this data source, so we caution that the confidence bounds on these estimates are likely narrow. We conducted a post-hoc evaluation of the association between a state's geographic position in its time zone and the predicted changes under the counterfactual scenarios. Using a linear regression model, we modelled the GAM-predicted percentage change in DVCs in response to latitude and relative longitude (relative to the solar central meridian, as detailed earlier). We fitted all simpler combinations of variables and ranked models using AICc.

To estimate differences in total costs under permanent DST and standard time, we multiplied the model-estimated difference in the number of DVCs by the average costs of a DVC (Table S5). We report costs of DVCs rather than all animal-vehicle collisions combined because approximately 90% of animal-vehicle collisions in the US involve deer,[3] and >99% of animal-related vehicle insurance claims submitted to State Farm involve deer.[27] To estimate the average cost of collisions, we separated collisions into the "KABCO" severity scale often used by police reports, where K = fatal injury, A = suspected serious injury, B = suspected minor injury, C = possible injury, and O = property damage only. Fifteen states categorized collisions into severity classes (Table S1), which we used to calculate the average rate of DVCs falling in each severity class (Table S6). It has been estimated that 8% of DVCs do not cause property damage[27]; we therefore included a category for "no property damage" (0.08) and reduced the other categories by a factor of 0.925 (1/1.08), such that all categories summed to 1 (Table S6).

We estimated comprehensive costs of DVCs in each severity class using previous cost estimates[57] (Table S6), converted to 2021 dollars using the US Bureau of Labor Statistics consumer price index inflation calculator (https://www.bls.gov/data/inflation_calculator.htm). Comprehensive costs include emergency services, medical costs, lost productivity, administrative and legal costs, and property damage. For collisions involving property damage only, we used the average cost of insurance claims for DVCs reported by State Farm in 2017,[58] which was $4,179 ($4,619 in 2021 USD), plus towing and animal removal costs ($229). We then calculated the average cost of a DVC by multiplying the proportion of collisions in each severity class by the estimated comprehensive cost, and then summed across KABCO classes for an average cost of $32,472, the majority of which comes from the very large costs associated with fatal collisions (Table S6).

We estimated the average rate of human injuries caused by DVCs by summing the proportion of DVCs for classes K, A, B, and C (Table S6), except we discounted category C (possible injury) by 50%, yielding an injury rate of 0.0562 human injuries per DVC. Discounting category C represents a conservative solution to the possibility that some collisions in this class did not lead to injury. To estimate the total change in injuries, we multiplied the injury rate by the model-estimated difference in DVCs. Finally, we calculated the expected change in human deaths by multiplying 0.0009 (Class K; Table S6) by the expected change in DVCs.