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A Reprieve from US wildlife mortality on roads during the COVID-19 pandemic

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ABSTRACT

High traffic volume is one of the main contributors to wildlife-vehicle collision (WVC) and wildlife mortality on roads. Government shelter-in-place (SIP) orders have been used to help mitigate the spread of COVID-19, resulting in unprecedented reductions in global traffic volumes. Using traffic and collision data from four US states (California, Idaho, Maine, and Washington), we investigated changes in total WVC, following the state and local SIP orders. From mid-March to mid-April 2020, these orders have resulted in up to 71%, 63%, 73%, and 72% reduction in driving, as measured by vehicle miles traveled (VMT), in CA, ID, ME, and WA respectively. The daily WVC rates from the 4 weeks prior to SIP orders going into effect, to the 4 weeks after, declined 34%, with 21, 36, 44, and 33% declines for CA, ID, ME, and WA, respectively. For mountain lions (*Puma concolor*) in CA, there was a 58% decline in mortality during the traffic reduction. The changes in WVC from 1 month pre-SIP orders to 1 month post-order only occurred in 2020 and not 2015, 2016, 2017, 2018, or 2019, suggesting that the reductions were associated with the reductions in traffic. The measured declines in WVC reversed in ME and WA during May, June and July 2020, paralleling reversals in traffic volumes. A 34% reduction in WVC would potentially equate to 10s of millions fewer vertebrates killed on US roadways during one month of traffic reduction, representing an unintentional conservation action unprecedented in modern times.

1. Introduction

Traffic causes a wide range of negative impacts on humans and nature, including traffic crashes and consequent injuries and fatalities; direct and indirect impacts of fuel extraction and use; fragmentation of wildlife habitat; wildlife-vehicle collision (WVC); and greenhouse gases and other emissions [Forman et al. \(2003\)](#). Mitigation of the spread of COVID-19 has been implemented by cities, counties, and governors' offices through "shelter-in-place" (SIP) orders and related actions (e.g., closure of non-essential businesses). These orders may have had impacts beyond controlling the virus – they may also be responsible for reduced environmental impacts, including traffic on minor and major roads. Traffic can be linked to many anthropogenic, environmental impacts

([Corlett et al. 2020](#)), which have been temporarily and dramatically reduced during the unintentional experiment of SIP orders. [Rutz et al. \(2020\)](#) proposed the term "anthropause" to describe this reduction in human activity and consequent impacts.

The presence of roads and traffic impacts wildlife abundance ([Fahrig and Rytwinski 2009](#)) and traffic volumes are tied to the risk and rates of WVC (e.g., [Litvaitis and Tash 2008](#)). However, the interaction between traffic volume and WVC may not be linear. In other words, intermediate traffic volumes may result in higher rates of WVC than large traffic volumes because wildlife may be more willing to attempt to cross roads and highways with moderate traffic than highways with frequent vehicles ([Seiler 2003](#)). Typically, studies of the effects of traffic volumes on WVC have compared data over years on the same roads (e.g., [Burson](#)

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et al. 2000; Fahrig et al. 2001; Nelli et al. 2018). For any given road, it is possible that if traffic volumes are radically reduced in a short time-frame, as has been the case for many US roads and highways during the COVID-19 pandemic, then rates of WVC may be proportionally reduced. For example, van Langevelde et al. (2009) proposed that in habitats fragmented by roads, traffic calming (reduced traffic volumes and speeds) would reduce mortality risks to wildlife in the calmed area and increase the likelihood of population persistence.

Although there have been no formal studies of the absolute or total rate of WVC (i.e., including different animal taxa) for most parts of the world, there have been estimates for vertebrates in general and for specific wildlife groups. For example, Forman and Alexander (1998) suggested that approximately 1 million vertebrates per day are killed on US roads and highways. There have been no estimates of total mammals killed on US roadways. This order of magnitude of mortality is supported by Loss et al. (2014) who estimated that 87 to 340 million birds are killed per year on roads in the US (9,834,000 km²). This is consistent with other estimates in the literature for total bird mortality on roads for European countries of 350,000 (Denmark, 42,933 km²) to 27,000,000 (UK, 242,490 km²) birds killed per year on roads (Erritzoe et al. 2003). It seems very possible that 100 s of millions of vertebrates (birds, reptiles, amphibians, and mammals) are killed per year on US roadways. During periods of low traffic volumes, it also appears possible that many millions of vertebrates may avoid mortality.

Studies of WVC, including proximate causes, total rates, seasonality and other properties have been aided by the emergence of large-extent WVC observatories (Shilling et al., 2020). These observatories provide two important types of data that are relevant to studies of changes in WVC in response to the pandemic: 1) rates of mortality of animals on roads from traffic and 2) evidence of species occurrence at species places and time. These observatories are increasingly relied upon to study wildlife populations and dynamics (Schwartz et al., 2020; Tiedeman et al. 2019).

In the current study, we investigated potential changes in impacts to wildlife from reduced traffic in 4 US states with advanced systems for tracking wildlife-vehicle collision (WVC): California (CA), Idaho (ID), Maine (ME), and Washington (WA). We defined three periods during the pandemic in 2020, based on a combination of traffic conditions and shelter-in-place orders: Period 1) pre-shelter-in-place (before mid-March), Period 2) during shelter-in-place (mid-March to mid-April), and Period 3) increase in activity (after mid-April until the end of July). We should note that the increase in traffic activity may have been related to government advice gradually reversing shelter-in-place guidance, or a perceived decline in the severity of the pandemic. We measured changes in traffic volumes and rates of WVC across the 4 states during these first 3 periods of the pandemic.

2. Methods

2.1. Study domain

The study areas were the whole territory of the US states California (CA), Idaho (ID), Maine (ME), and Washington (WA), which were chosen because they are geographically positioned across the US and because they each have up-to-date databases of WVC reports. The total area of these states is ~914,000 km², representing 9.3% of the US. The study time periods for each state were chosen based on a combination of the SIP orders and the approximate date when traffic levels declined. The state orders were published: CA, 3/19/2020; ID, 3/25/2020; ME, 3/31/2020; and WA, 3/23/2020. For all states, the pre-SIP, Period 1, was defined as February 17 to March 15, inclusive. The SIP period, Period 2, was defined as March 21 to April 18, inclusive. The start date for Period 2 was chosen because in every state traffic had dramatically declined by this point, even if a SIP was not yet in place. There was a gap between the end of Period 1 and the start of Period 2 to allow traffic to decline to a lower level. In other words, traffic declined with a slope and did not

abruptly change. The post-SIP recovery period, Period 3, was defined as April 19 to July 31 at the latest, depending on data availability for the parameter. For CA, ID, and WA, data were available until July 31, 2020. For ME, data were available to June 30, 2020.

2.2. WVC datasets

Datasets were collected for each state from their respective WVC data managers: CA, Road Ecology Center, UC Davis; ID, Idaho Department of Fish and Game; ME, Maine Department of Transportation; and WA, Washington State Department of Transportation. All datasets contained location, date/time, and the terrestrial mammal species or species group (e.g., "deer") involved in the WVC incident. Across all four states, a substantial proportion of wildlife involved in these incidents were ungulates. For CA we used data collected by the Road Ecology Center's California Highway Incident Processing System (CHIPS) from California Highway Patrol reports. CHIPS is an automated, real-time data retrieval system for all incident data reported by the California Highway Patrol, which includes data from February 2, 2015 until 15 minutes before present and includes all state highways and many major county roads. For January – July 2020, these data included 2444 observations for 14 species, 77% of which were ungulates. For ID, we downloaded data from the Idaho Fish and Wildlife Information System (IFWIS). We selected only observations by Idaho Department of Transportation and Idaho Department of Fish and Game staff, because their effort of reporting did not change during the 3 Periods, whereas public observation effort may have varied during the study period. These data included 1464 observations of 26 species in 2020, 92% of which were ungulates. For ME, we requested and received data from the Maine Department of Transportation, which were primarily from Maine State Police. There were 2056 observations of 3 species for January to June 2020, 99% of which were for two ungulates (white-tailed deer, *Odocoileus virginianus*, and moose, *Alces alces*). For WA, data were requested and received from the Washington State Department of Transportation (WSDOT). These data were collected by WSDOT staff as they collected carcasses from roads. For January to July 2020, there were 3675 observations of 26 species, 57% of which were for ungulates. For mountain lion (*Puma concolor*) mortalities, we used a dataset that was jointly developed by the Road Ecology Center, Winston Vickers (UC Davis) and California Department of Fish and Wildlife, which included 33 observations for January to June 2020. All WVC data were manually reviewed for record duplication and spatial accuracy (i.e., located on a roadway). Co-authors from each of the 4 states confirmed with the carcass collection programs in each state that there was no change in carcass collection effort and reporting during the study period. In all 4 states, observations of carcasses and crashes involving wildlife were made by state wildlife, state transportation and state police staff.

2.3. Traffic conditions

Two types of traffic condition data were collected: 1) traffic counts from roadway monitoring stations maintained by each state's Department of Transportation, and 2) total vehicle miles traveled (VMT) for each day, for all roads each US county. These two data types conceptually overlap, but are collected with different methods. 1) All states employ loop detectors to measure traffic volumes on state highways, which are defined here as highways managed by US state agencies and are usually un-fenced. Volume data for individual traffic monitoring stations on 11 state highways in California were retrieved from the Performance Monitoring System (<https://pems.dot.ca.gov>) up to July 4, 2020. The system was inoperable after that point and until this writing, precluding more data retrieval. Monthly traffic count data for ID were obtained for 15 state highways from an online resource, for January to July 2020 (<https://itd.idaho.gov/road-data/>). Monthly traffic count data for ME were not available for individual highways, but were available as a monthly aggregate estimate from MaineDOT traffic

operations for January to July 2020. Traffic volumes for 14 state highways in WA were collected from an online resource provided for information related to COVID-19 for January to July 2020 (<https://www.wsdot.wa.gov/about/COVID-19-transportation-report/dashboard/highway/default.htm>). 2) Daily VMT data for each US state and county for the period 3/1/2020 to 7/31/2020 were obtained from StreetLightData (<https://Streetlightdata.com>) by requesting a dataset from the company. Only data after March 1, 2020 were available. The VMT estimates are based on the movement of ~110 million mobile device GPS in US and Canada, are validated using traffic counter data, where possible (StreetLight Data, 2020) and are potentially useful for estimating traffic on un-monitored roads (Mauch and Skabardonis 2020).

2.4. Analyses

Changes in traffic volumes in Period 2 were calculated as a percent change from Period 1 traffic volumes. We compared total numbers and rates of WVC before and after the respective SIP orders for each state, from Period 1 to 2, as well as the trend in WVC following gradual increase in traffic after mid-April. All analyses were conducted using RStudio (ver. 1.3.959; R Core Team 2014). Because of possible seasonal changes in wildlife movement and location occupancy, the time periods chosen for analysis of change following SIP orders were relatively short: 28 days before and after the order and after traffic volumes were < 80% of the average volume in January 2020. For mountain lions, we used a longer time period (10 weeks before and after) due to the low rate (~2/week) of WVC reports for this species. The differences between the date of the order and reduced traffic volume varied between 1 day (CA, ID) and 11 days (ME). Statistical significance of changes in traffic conditions and WVC were measured using the two-tailed *t*-test for Period 1 and 2 comparisons and using the linear model (lm) function during the upward trend in traffic after mid-April. For all states, by April 19th, traffic volumes was increasing, so this date was chosen as the start of the upward trend period (Period 3). The Simpson Diversity Index was calculated using the diversity function in R.

3. Results

3.1. Change in total vehicle miles travel

The total miles traveled in the first week of March in the US was 103 billion miles, whereas the total miles traveled in the second week of April was 29 billion miles. This 71% reduction in total miles traveled was reflected in the range of reductions seen across each state in this study. State highway VMT on all roads in each of CA, ID, ME, and WA significantly declined by up to 71%, 63%, 73%, and 72%, respectively (Fig. 1).

After mid-April, traffic volumes in US states began increasing to levels similar to before the stay-at-home guidance (Fig. 1), but VMT may have stabilized at slightly different proportions to January VMT relative to each other. Between April 19 and July 5, 2020, VMT had returned to 80% (CA) to >100% (ID) of January levels.

3.2. Change in highway traffic flows

For CA, ID and WA, daily (CA and WA) or monthly (ID) highway traffic volumes were available from traffic loop detectors. For ME, there have been press releases from MaineDOT regarding reductions in traffic and one quantification of changes in total state highway volumes between January and July 2020 (personal communication, MaineDOT Traffic Operations). The change in measured highway traffic volume ranged from 11% (ID) to 41% (WA) and averaged 30% across all 4 states (Table 1).

3.3. Reduction in impacts to wildlife

Co-occurring with reductions in VMT and highway traffic volumes were statistically-significant reductions in collisions with wild animals between Period 1 and 2 of 21%, 38%, 44% and 33% for CA, ID, ME and WA (Table 2). We also analyzed rates of WVC in previous years (2015, 2016, 2017, 2018, and 2019) and for the same time periods, there were either statistically-significant increases ($p < 0.05$), or no change in

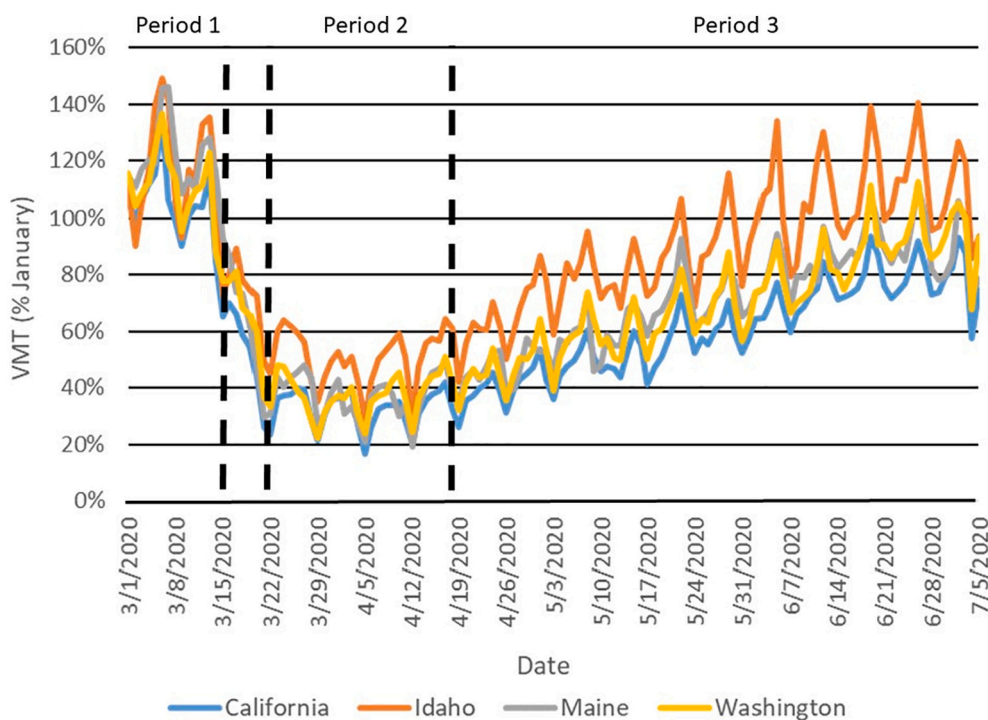


Fig. 1. Change in daily vehicle miles traveled (VMT) for CA, ID, ME, and WA between March 1 and July 5, 2020. Percent change in VMT is in comparison to January VMT.

Table 1

Changes in state highway and interstate traffic volumes expressed as percent change from one period to another. Data were not available for most of Period 3, so no comparison was made between Periods 2 and 3 for ID.

State	Change, Period 1 to 2	Change, Period 2 to 3
CA	-32.8%	+41.5%
ID	-11.0%	N/A
ME	-35% ^a	+53.5%
WA	-41.2%	+27.5%

^a Estimated based on personal communication from MaineDOT Traffic Operations of their calculated changes.

numbers of WVC before and after the date of each state’s order in any of these previous years. An important point is that these numbers represent the numbers of large wildlife reported killed in collisions (e.g., mule deer, *Odocoileus hemionus*; white-tailed deer; moose; elk, *Cervus Canadensis*; black bear, *Ursus americanus*; coyote, *Canis latrans*; mountain lion) and do not represent all collisions with large wild animals, or with all wild animals of any size. It should also be noted that, in every case, we confirmed that the effort of reporting carcasses or crashes had not changed before and after the order suggesting the reductions are not due to fewer government staff reporting carcasses or crashes with wild animals.

3.4. Reduction in impacts to mountain lions

Mountain lions are reported hit on California roads and highways up to twice per week. In a typical year, this rate either stays constant or increases slightly in the transition from winter to summer. We found that the rate of mountain lion mortality declined 58% ($p = 0.030$) between the 10 weeks prior to the state order and the 10 weeks after. The rate of mortality during the post-order period in 2020 was also significantly lower than rates for the same period during the preceding two years ($p < 0.04$) (Table 3).

3.5. Species diversity of WVC

One possibility is that the species and numbers of individuals per species impacted by normal and reduced traffic volumes would be different. The Simpson species diversity index (SI) of WVC in CA, ID, and WA did not change substantially between Periods 1 and 2, suggesting that impacts to species were similar before and after the reduction in traffic. For CA, the SI in Periods 1 and 2 were 0.40 and 0.36, respectively; for ID, the SI in Periods 1 and 2 were 0.64 and 0.72, respectively; and for WA, the SI in Periods 1 and 2 were 0.87 and 0.90, respectively. Maine only reported WVC for 3 species so was not considered.

4. Discussion

Recent studies and opinion pieces have highlighted the various unintended consequences of COVID-19 mitigation for nature through state and regional stay-at-home and shelter-in-place guidance (Arora et al. 2020; Manenti et al. 2020; Zellmer et al. 2020). Recently, Bates et al.

Table 2

Change in daily rates of wildlife-vehicle collisions (standard deviation) for Period 1 and Period 2. * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$, n.s. indicates not significant.

	CA		ID		ME		WA	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
2020	9.86 (3.97)	6.93 (2.29)**	7.57 (5.07)	4.89 (5.84)*	12.7 (6.14)	7.82 (2.50)***	16.4 (6.83)	10.5 (5.51)**
2019	9.04 (3.18)	9.71 (4.50)n.s.	9.61 (6.02)	9.46 (5.84)n.s.	11.4 (3.57)	17.9 (7.68)***	21.2 (7.09)	16.6 (10.8)n.s.
2018	7.71 (4.67)	10.4 (4.77)*	5.46 (3.63)	7.5 (3.49)n.s.	11.7 (6.66)	17.1 (6.02)**	16.4 (7.32)	15.4 (11.8)n.s.
2017	10.5 (4.02)	9.14 (7.36)n.s.	8.29 (6.60)	6.89 (5.60)n.s.	11.4 (6.18)	15.6 (6.09)*	21.8 (11.0)	15.6 (12.2)n.s.
2016	9.04 (6.19)	14.7 (5.60)***	5.82 (3.70)	9.18 (13.3)n.s.	8.29 (3.18)	8.00 (3.08)n.s.	15.9 (8.59)	14.2 (11.6)n.s.
2015	10.0 (3.62)	11.5 (6.67)n.s.	9.61 (5.74)	8.21 (3.78)n.s.	5.39 (3.00)	17.7 (6.90)***	ND	ND

(2020) proposed that it is critical to understand the impact of “human confinement” on biodiversity conservation. There are 4 proposed mechanisms for how human confinement could affect biodiversity conservation domains (e.g., policy): commuting, supply chains, food transport, and recreational activities. All 4 hinge to varying degrees on road traffic. So far, there has not been a quantification of the impacts to wildlife from reduced human activity, especially road traffic. We show here that there was a statistically-significant 34% reduction in the number of large wild animals killed per day on US state highways, for 4 US states, that coincided with the reduced traffic following state shelter-in-place guidance. This reduction is similar to the 14% to 45% reduction in WVC found by Bil et al. (this issue) for 11 European countries during the COVID-19 related traffic reduction. It seems likely that the reduction was due to reduced roadway traffic and that this positive impact occurred in other states beyond the four studied and for other animals besides large mammals. The change also occurred over a very short time period when traffic was dramatically reduced and was not reflected in previous years during the same time period. A study by Manenti et al. (2020) suggested that traffic reductions may especially benefit terrestrial migrators such as certain species of herpetofauna, many of which are endangered. Given the five to nine-fold under-reporting of large animals involved in collisions with vehicles (Donaldson 2017; Olson et al. 2014) and the lack of systematic reporting of smaller animals killed on roads, the positive impacts we report are likely to be just the tip of the iceberg of reduced deaths of wildlife on US roads and highways.

4.1. Change in human activity

The 71% decrease in VMT for all travel on all roads for CA, ID, and WA, was greater than the estimated 30% change in traffic volumes on 40 state highways, suggesting that driving patterns may be quite different on local roads and state highways. Alternatively, the different methods and locations of data for the estimates of traffic amounts could be the explanation for the large discrepancy. The VMT data used here were estimated by movement of mobile phones and the highway traffic volume data by loop-detectors counts of individual vehicles. The difference suggests that resolution is needed of what the true reduction in traffic volumes has been and whether there are differences in reductions between state and minor roads.

Table 3

Rate of mountain lion mortality on CA roads and highways in 2020, 2019, 2018, 2017, and 2016, before and after the dates of the state SIP orders. * indicates $p < 0.05$, n.s. indicates not significant.

Year	Mortality/day Period 1	Mortality/day Period 2	% Change	P-value/significance
2020	0.27	0.11	-58	0.030/**
2019	0.19	0.26	0	0.40/n.s.
2018	0.21	0.23	0	0.88/n.s.
2017	0.17	0.21	0	0.57/n.s.
2016	0.11	0.10	0	0.79/n.s.

4.2. Consequence for wildlife and biodiversity conservation

Traffic reductions during March–July 2020 in US states were accompanied by statistically-significant reductions in the number of WVC. We found that for CA, ID, ME, and WA the number of WVC recorded as crashes or carcasses in statewide WVC-reporting systems declined statistically between the four weeks prior to the stay-at-home order and the four weeks after the order. This is in contrast to previous years (2015 to 2019), where WVC rates in this time period usually either stayed constant or increased during the transition from winter to spring. We suggest that the reductions for certain states and species represent a far more spatially extensive reduction in WVC, as well as the full range of species killed on roads by vehicles. Very few states have observation systems for all species found dead on roads, with California and Maine possibly being the only two (Waetjen and Shilling 2017). However, the consistency of the patterns among the 4 US states studied suggests that any species typically killed by traffic will have had reduced rates of mortality during the pandemic-induced traffic reduction. Beyond outright wildlife injuries and mortalities, the reduction in traffic may have had other indirect effects on wildlife connectivity and populations, such as improving gene flow or decreasing the spread of infectious diseases (Zellmer et al. 2020; Forti et al. 2020), effects which necessitate further studies.

Previous research has shown that collisions with deer and other large wildlife can be under-reported in the US to police and others by five to nine fold (Donaldson 2017; Olson et al. 2014). In 2019, CA, ID, ME, and WA recorded at least 5443 (mule deer only), 4530, 5808, and 5840 collisions with large mammals per year, respectively. This suggests that 27,000–49,000 large mammals are killed per year on CA roads and highways, as well as an unknown number of other species. This is supported by the State Farm Insurance Co. estimate of >23,000 claims/year for collisions with deer resulting in claims in California (<https://newsroom.statefarm.com/download/234883/allstates2015-16deerstats-fin-alpdf.pdf>). It is likely that there are also collisions that do not result in insurance claims. If we used a conservative under-reporting rate of five-fold, then it is possible that the reported collisions represent 27,200, 22,650, and 29,040 and 29,200 deer and other large mammals killed on roads and highways per year in CA, ID, ME, and WA, respectively. The 34% reduction we observed during the traffic reduction period would represent 5712, 8607, 13,068, and 11,680 fewer deer and other large mammals killed per year in CA, ID, ME, and WA, respectively.

Mountain lions in CA experienced a 58% reduction in mortality on roads at a time when the state is considering legal protection for the species, in part because of lion-vehicle collisions. There are three primary threats to the species: 1) state-permitted killing of mountain lions that may have attacked domestic animals, 2) mortality from road and highway traffic, and 3) population fragmentation by busy highways. Sub-populations face local extinction in CA due to isolation within encircling highways (Benson et al. 2019). Vehicle strikes are the primary risk to a sub-species of mountain lion, the Florida panther (*P. concolor coryi*; Onorato et al. 2010). According to the Florida Fish and Wildlife Commission (FFWC), a reduction in wildlife-vehicle strikes was observed for Florida panther in 2020, with no strikes observed in Period 2 when there are typically 4–6 during this period, approximately the same number as during Period 1 (unpublished observations, “Panther Program”, FFWC). One significant impact of this finding for mountain lions is the clear link between traffic and rates of mountain lion death. This means that to reduce mountain lion mortality, populations must be protected from traffic, especially in the San Francisco Bay Area and Southern California where isolated and small populations of mountain lions are at risk of extinction. Protection from traffic has been accomplished in CA and other places by building wildlife crossings associated with fencing. Jacobson et al. (2016) suggested that, based on behavioral analyses of mountain lions and other wildlife, crossings would ideally be situated even at sites with low traffic volume, and where topography softens traffic effects. Proposed legal protection for the mountain lion in

California, combined with more extensive systems of crossings and fences will help reduce threats to this species once the mortality respite from reduced traffic is over.

Large mammals are likely to be only a small proportion of vertebrates killed on roads. Estimates range from 1 million vertebrates per day killed on US roadways (Forman and Alexander 1998), to 87 to 340 million birds per year (Loss et al. 2014). Given these published studies, it seems very possible that 100 s of millions of vertebrates (birds, reptiles, amphibians, and mammals) are killed every year on US roadways, equating to more than 10–30 million per month. A 34% reduction in this mortality for one or two months in 2020 could have represented millions of vertebrates not being killed on US roads, and though unintentional, could be among the largest conservation actions ever taken in the US since the formation of the National Park System.

4.3. Importance of biodiversity observatories

Corlett et al. (2020) proposed that the pandemic impacts and responses has pointed to the need for conservation biology to be ready with rapid-response research to support society. Our findings and those of Bil et al. (this issue) would not have been possible without years of WVC observations preceding the pandemic and continuing observations during the pandemic. Roads and WVC are prevalent throughout the world and offer a continuing record of nearby terrestrial vertebrates. Observatories created to monitor WVC are critical for understanding the impact of WVC on absolute and relative changes in population size (Fährig and Rytwinski 2009) and the impact of sudden or large changes in traffic (present study and Bil et al., 2021; this Special Issue). WVC observatories are expanding and becoming more sophisticated, employing modern informatics, data management and visualization, and decision-support protocols (Shilling et al., 2020). For example, the systems in California employ a combination of automated data collection from online reporting from California Highway Patrol in real time and volunteer-contributed observations of carcasses (Waetjen and Shilling 2017; Shilling et al., 2020). We suggest that supporting observatories like the ones used in this study is vital to understanding and responding to many contemporary conservation challenges, as well as to measuring the benefits from intentional or unintentional changes in anthropogenic impacts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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