TRACKING MOOSE- AND DEER-VEHICLE COLLISIONS USING GPS AND LANDMARK INVENTORY SYSTEMS IN BRITISH COLUMBIA

Caleb Sample[1], Roy V. Rea[1], and Gayle Hesse[2]

[1]University of Northern British Columbia, 3333 University Way, Prince George, British Columbia, Canada V2N 4Z9; [2]Wildlife Collision Prevention Program, British Columbia Conservation Foundation, 4431 Enns Road, Prince George, British Columbia, Canada V2K 4X3.

ABSTRACT: Vehicle collisions with moose (*Alces alces)* and deer (*Odocoileus* spp.) pose a serious threat to all motorists travelling highways traversing habitats of these two ungulates. In British Columbia, mitigation measures to reduce such collisions are based on spatially-accurate records of collisions involving moose and deer that are collected by the province's highway maintenance contractors. To date, the British Columbia Ministry of Transportation and Infrastructure (BC MOTI) uses the paper-based Wildlife Accident Reporting System (WARS) established in 1978 to maintain carcass records. We compared carcass location data collected in 2010 to 2014 by BC MOTI using WARS to that collected by Northern Health Connections bus drivers using a newly developed GPS-based system (Otto® Wildlife device). In total, 6,929 carcasses (1,231 moose, 5,698 deer) were recorded using WARS and 474 (167 moose, 410 deer) using the Otto® Wildlife device. We compared data collected along 2,800 km on the same highways in the same seasons of the same years. We found more carcass locations were identified with the WARS method, but that in certain geographic regions, the Otto® Wildlife system identified several unique locations. We contend that more complete and finer-scale carcass location data is possible using a GPS-based system such as Otto® Wildlife, than currently collected solely with the paper-based WARS method.

ALCES VOL. 56: 49–61 (2020)

Key Words: *Alces*, car, collision, deer, GPS, moose, *Odocoileus*, roadkill, survey, vehicle

British Columbia is a province richly inhabited by large mammals and where populations are abundant and highways traverse their habitat, wildlife vehicle collisions (WVC) are a management concern. Between 2013 and 2017, annual collision records from the Insurance Corporation of British Columbia (ICBC) averaged 11,000 animal-related crashes, with ~700 human injuries and 3 fatalities (ICBC 2018). In addition to the safety threat resulting in $41 million in ICBC insurance claims, the annual value of wildlife-specific mortality is estimated at $466 million (Sielecki 2010). Spatially-accurate, comprehensive WVC records are critical to limit threats to motorists (Huijser et al. 2007) and to provide valuable insights about spatial and temporal WVC patterns useful to implement specific WVC mitigation measures.

The British Columbia Ministry of Transportation and Infrastructure (BC MOTI) uses the Wildlife Accident Reporting System (WARS) to document when and where wildlife carcasses occur and are collected throughout the province. Highway maintenance contractors are required to remove carcasses from numbered highways and submit a monthly, paper-based report to BC MOTI through WARS (Sielecki 2010). Maintenance contractors use date-of-carcass retrieval and the Landmark

Kilometre Inventory (LKI) (BC MOTI 2018b) to record the removal locations. At the time of our study, the carcass reporting methodology in WARS had remained largely unchanged since its inception in 1978. Several weaknesses have been identified previously including imprecise collision locations and incorrect and incomplete reporting of wildlife species (Sielecki 2010).

To determine how WARS data collected under the current system might differ from a GPS-based electronic record-keeping system, we partnered with PerSen Technologies Inc. (PERSENTECH) in Winnipeg, Manitoba to develop the Otto® Wildlife GPS unit (Fig. 1; Hesse et al. 2010). This device was specifically designed to capture real-time GPS coordinates, and the time and date of sightings of dead and live moose (*Alces alces*) and deer (*Odocoileus* spp.; mule, white-tailed, and black-tailed deer all referred to as “deer”), which together comprised 83.1% of WVCs in 2003–2007 (Sielecki 2010). Units were designed for dash-mounting with push button controls to enter data (including sound replay) without requiring the operator of the device to stop their vehicle. We partnered with the Northern Health Authority and Diversified Transport of Prince George and installed Otto® Wildlife devices on the dashboards of Northern Health Connections buses for drivers to collect data on deer and moose throughout the province.

Fig. 1. The Otto® Wildlife GPS device used for capturing location data for live and dead deer/moose. The unit is powered by two AA batteries or can be plugged into the vehicle’s accessory receptacle.

To determine the usefulness of GPS technology in WVC mitigation planning, we compared the similarity of moose and deer WVC data collected with WARS and Otto Wildlife on selected highways. Our null hypothesis was that both methods produced similar temporal and spatial patterns for moose and deer WVCs.

STUDY AREA

Our study area was located in British Columbia, Canada, extending from Abbotsford in the south to Fort St. John in the north (Hwys 1 and 97) and from Prince Rupert on the Pacific west coast to Valemount (Hwys 5 and 16) in east-central British Columbia near the Alberta border, a total of 2,798 km of highway. It is recognized that variable widths in right-of-ways likely influenced detection rates at certain locations on all highways. The north and east sections of the study area are characterized by rugged, mountainous terrain with deeply incised valleys (Child 1992), with terrain to the south and west flat to rolling with hundreds of small lakes and wetlands (Heard et al. 1997). Although mostly an homogeneous unit on a drumlinized till plateau surrounding periglacial lake deposits, it is dissected by many rivers, lakes and wetlands (Child 1992) and divided by the Rocky Mountains in the north and east. The landscape is dominated by coniferous forests of hybrid white spruce (*Picea engelmannii* x *glauca)* and subalpine fir (*Abies lasiocarpa)*. Lodgepole pine (*Pinus contorta* var. *latifolia)* and trembling aspen (*Populus tremuloides)* pioneer secondary successional sites (Meidinger and Pojar 1991), as do many species of willows (*Salix* spp.) and other woody browse plants used by moose and deer. Moose densities in the core of our study area were estimated at 0.63–0.78 moose/km^2 (Cadsand et al. 2013); deer densities were unknown.

METHODS

Otto® Wildlife System

The Otto® Wildlife device provided GPS locations of carcasses and additional information about the animal. To record a live sighting, the appropriate species button (Fig. 1) was pressed to activate a coloured LED and a vocal playback of "deer" or "moose" to confirm that the correct species was recorded by the operator. To catalog a carcass, the "dead button" was pressed immediately after the species button. Pushing the "dead button" 3 times allowed the driver to indicate that a record was in error. Latitude, longitude, time of day, and date were recorded when any of three buttons designed to collect data were pushed.

Previous to our study, and to verify that the Otto® Wildlife devices were recording accurate locations of carcasses and live sighting points of interest (POI), Hesse et al. (2010) compared Otto® Wildlife POI locations to existing government GIS layers and found that only 1.5% of Otto® Wildlife location data were ≥10 m from the Digital Road Atlas (DRA) layer (https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/roads). This study also confirmed (via exit interviews), that Otto® Wildlife did not pose a safety concern to vehicle operators and that the units were performing as per their intended design.

The University of Northern British Columbia partnered with the Northern Health Authority to dash-mount Otto® Wildlife devices in 10 Northern Health Connections buses. Data were subsequently collected by bus drivers for live and dead moose/deer and reported to bus dispatchers from 10 June 2010 to 15 July 2014. We collected data from dispatchers every 3–6 months and converted Otto® Wildlife and WARS data from the same time period to KMZ (Keyhole Markup Language Zipped) map files to compare moose and deer carcass data from the two methods. Because the WARS data only contained carcass records, we made no comparison of live sightings. An inevitable source of error associated with this method of comparison was that bus drivers operated on set schedules, driving certain sections of highway once daily, while maintenance contractors patrolled highways and responded to WVC reports 24 h/d, 7 days a week. Therefore, from the outset of the study, we acknowledged maintenance contractors patrolling routes driven by busses would record more carcasses than bus drivers.

Carcass data were sorted and organized using Microsoft Excel. Records within 500 m of each other were identified using ArcGIS in a BC Albers 1983 coordinate system and Quantum GIS Desktop distance matrix tool, with a linear output matrix type (set within the QGIS Distance Matrix Tool; QGIS 2.4 Development Team 2014) and were deemed to be possibly referencing the same carcass (Hyrcha and Rea, unpublished). All carcass records within 500 m of each other were further evaluated for duplication using the following criteria: carcasses recorded <2 min apart of each other by the same driver on the same date were considered individual sightings of distinct animals, and both records were retained. It was considered highly probable that records of the same species at the same location occurring between 2 min and 24 h of each other were recorded by different busses; therefore, these records were classified as the same carcass (recorded twice) and one record was discarded. We accounted for location and time to determine whether same-species records occurring 1–7 days apart were duplicate sightings. For example, two records in close proximity on a stretch of highway with a very low WVC rate were deemed likely as duplicates. A spatial map of carcass locations created with Google Fusion Tables identified concentrations or hotspots of MVCs (Fig. 2).

WARS

We obtained WARS data for the same period and along the same highways where Otto® Wildlife devices were used. These data were not georeferenced, but provided written records of carcass locations using a series of established landmarks along highways. Therefore, these locations had to be georeferenced in Google Earth using the Landmark Kilometer Inventory (LKI; BC MOTI 2018b). We created KMZ mapping files for both WARS and Otto® Wildlife data and overlaid them for comparison. We then visually inspected and analyzed the area around each Otto® Wildlife and WARS record to identify matches.

Comparison of Otto® Wildlife and WARS

We first considered the spatial proximity of the WARS and Otto® Wildlife records. Because the majority of LKI landmarks occurred within 1 km (BC MOTI 2018b), our first sorting criteria was a maximum separation of 1 km. However, because it was possible that the WARS spatial data included errors > 1 km, we evaluated matching of the datasets using maximum possible separation distances of 1, 3, and 5 km (S1, S3, S5).

Separation in recording dates between WARS and Otto® Wildlife records was also used to identify matched records. For each of the 3 spatial sortings, we allowed maximum temporal separations of 1, 3, and 5 days (T1, T3, T5) between matching records from the two databases. We combined the S and T values to simultaneously specify a record's spatial and temporal sorting. For example, a spatial and temporal range of 3 km and 5 days had the sorting criterion S3T5. Comparative analyses were performed separately for the 9 different sorting criteria (S1T1–S5T5). Moose and deer carcass records from the Otto® Wildlife devices were also categorized by 4 seasons of 3-month increments: spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February).

After comparing the Otto® Wildlife and WARS data to identify matching records, the data were sorted by time of year, latitude, highway, and separation of carcass location and time. To supplement the numerical data, geographic illustrations of carcass and live sighting locations (for Otto® Wildlife only) were constructed using the online application "MapMaker" (MapMaker.com 2018).

RESULTS

A total of 167 moose and 410 deer carcasses were recorded using Otto® Wildlife devices, and 1,231 moose and 5,698 deer carcasses with WARS. With the most relaxed sorting criterion of up to 5 km and a 5-day separation in reporting (S5T5), 20% and 27% of Otto® Wildlife moose and deer were classified as having a match with WARS data; with the strictest criterion (S1T1) these matches were 15% and 10%, respectively.

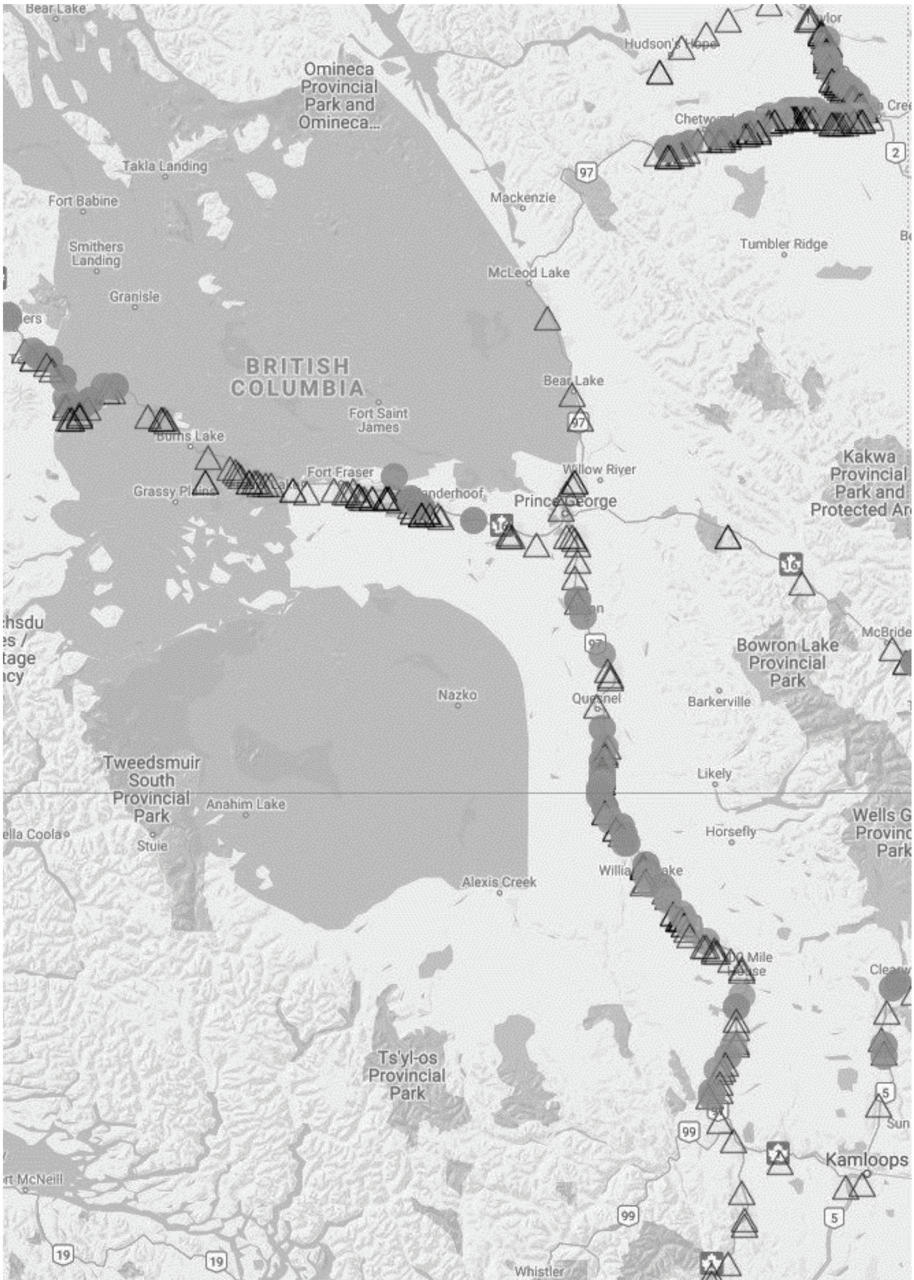

Fig. 2. A mapped sample of data from the middle of the study area (north-central BC) using S5T5 (spatial separation and temporal separation of 5 km and 5 days) Otto® Wildlife deer carcass records, with circles indicating Otto® Wildlife records with a corresponding WARS record (matching), and triangles indicating unique, unmatching Otto® Wildlife records (MapMaker.com, 2018).

The averages across all sorting criteria were 16% and 21% of moose and deer records, respectively (Table 1).

Moose carcasses were most commonly recorded during winter (n = 48) and fall (n = 45) with fewer in summer and spring.

Table 1. The number of matched/unmatched records of deer and moose carcasses by sorting criteria as collected with the Otto® Wildlife and WARS systems in 2010–2014, British Columbia, Canada. The sorting criteria indicate spatial (S; 1, 3, 5 km) and temporal separations (T; 1, 3, 5 d) used to determine matches.

Sorting criteria	Matched # Otto® deer	Unmatched # Otto® deer	Matched # Otto® moose	Unmatched # Otto® moose	Matching (%) with WARS (deer, moose)
S5T5	110	300	33	134	27, 20
S5T3	95	315	31	136	23, 19
S5T1	87	323	25	142	22, 15
S3T5	104	306	32	135	25, 19
S3T3	92	318	30	137	22, 18
S3T1	83	327	25	142	20, 15
S1T5	68	342	22	145	17, 13
S1T3	65	345	20	147	16, 12
S1T1	60	350	16	151	15, 10
Ave.					21, 16

Table 2. The number of matched/unmatched records of moose carcasses by sorting criteria and season as collected with the Otto® Wildlife and WARS systems in 2010–2014, British Columbia, Canada. The sorting criteria indicate spatial (S; 1, 3, 5 km) and temporal separations (T; 1, 3, 5 d) used to determine matches. Values are shown separately for records with and without matching WARS records.

Sorting criteria	Matched (n = 16–33)				Unmatched (n = 134–151)			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
S5T5	2	4	16	11	31	37	29	37
S5T3	2	4	14	11	31	37	31	37
S5T1	1	2	13	9	32	39	32	39
S3T5	2	4	15	11	31	37	30	37
S3T3	2	4	13	11	31	37	32	37
S3T1	1	2	13	9	32	39	32	39
S1T5	1	4	10	7	32	37	35	41
S1T3	1	4	8	7	32	37	37	41
S1T1	1	2	8	5	32	39	47	43
Ave.	3	7	26	19				

The number of Otto® Wildlife moose carcasses with a matching WARS record varied by season. The average matching rate was much higher in winter (26%) and fall (19%) than in spring (3%) and summer (7%) (Table 2). Most deer carcasses were recorded in fall (n = 131), winter and spring had similar levels of reporting, and summer had the lowest level (n = 82) (Table 3). As with moose carcasses, the rate of matching varied by season with highest matching in spring (26%) and lowest in winter (15%) (Table 2).

Matching moose and deer Otto® Wildlife carcasses and proportions were summarized based on the highway traveled (Tables 4 and 5). Carcasses of both species were most frequently recorded along Highway 97 (103 moose, 296 deer) and Highway 16

Table 3. The number of matched/unmatched records of deer carcasses by sorting criteria and season as collected with the Otto® Wildlife and WARS systems in 2010–2014, British Columbia, Canada. The sorting criteria indicate spatial (S; 1, 3, 5 km) and temporal separations (T; 1, 3, 5 d) used to determine matches. Values are shown separately for records with and without matching WARS records.

Sorting criteria	Matched (n = 60–110)				Unmatched (n = 300–350)			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
S5T5	34	22	38	16	69	60	93	78
S5T3	28	20	31	16	75	62	100	78
S5T1	27	16	29	15	76	66	102	79
S3T5	32	21	35	16	71	61	96	78
S3T3	28	19	29	16	75	63	102	78
S3T1	26	15	27	15	77	67	104	79
S1T5	25	13	18	12	78	69	113	82
S1T3	22	13	18	12	81	69	113	82
S1T1	21	11	17	11	82	71	114	83
Ave.	26	21	21	15				

Table 4. The number of matched/unmatched records of moose carcasses by sorting criteria and highway (H) as collected with the Otto® Wildlife and WARS systems in 2010–2014, British Columbia, Canada. The sorting criteria indicate spatial (S; 1, 3, 5 km) and temporal separations (T; 1, 3, 5 d) used to determine matches. Values are shown separately for records with and without matching WARS records.

Sorting criteria	Matched (n = 16–33)					Unmatched (n = 134–151)				
	H 2	H 5	H 27	H 16	H 97	H 2	H 5	H 27	H 16	H 97
S5T5	1	1	0	8	23	1	5	1	47	80
S5T3	1	1	0	8	21	1	5	1	47	82
S5T1	1	1	0	7	16	1	5	1	48	87
S3T5	1	1	0	8	22	1	5	1	47	81
S3T3	1	1	0	8	20	1	5	1	47	83
S3T1	1	1	0	7	16	1	5	1	48	87
S1T5	0	1	0	6	15	2	5	1	49	88
S1T3	0	1	0	6	13	2	5	1	49	90
S1T1	0	1	0	5	10	2	5	1	50	93
Ave.	50	17	-	13	17					

(55 moose, 97 deer); lower numbers were recorded on Highways 2, 5, and 27. The proportion of matching Otto® Wildlife records were similar on Highways 16 and 97, with average matching rates of 13% and 17% for moose (Table 4), and 18% and 21% for deer (Table 5).

Certain areas along Highway 97, such as between Quesnel and Williams Lake had a large proportion of matched deer carcasses; conversely, other areas had low matching rates. A low proportion of Otto® Wildlife and WARS records were matched on Highway 16 (Fig. 3), where – between

Table 5. The number of matched/unmatched records of deer carcasses by sorting criteria and highway (H) as collected with the Otto® Wildlife and WARS systems in 2010–2014, British Columbia, Canada. The sorting criteria indicate spatial (S; 1, 3, 5 km) and temporal separations (T; 1, 3, 5 d) used to determine matches. Values are shown separately for records with and without matching WARS records. Highway 27 had only one recorded carcass.

Sorting criteria	Matched (n = 60–110)				Unmatched (n = 300–350)			
	H 5	H 16	H 27	H 97	H 5	H 16	H 27	H 97
S5T5	7	19	1	83	9	78	0	213
S5T3	7	18	1	69	9	79	0	237
S5T1	7	17	1	62	9	80	0	244
S3T5	6	18	1	79	10	79	0	217
S3T3	6	17	1	68	10	80	0	220
S3T1	6	15	1	56	10	82	0	232
S1T5	5	16	1	46	11	81	0	250
S1T3	5	15	1	44	11	82	0	252
S1T1	5	15	1	39	11	82	0	257
Ave.	38	18	-	21				

Fig. 3. An example from north-central BC of a particularly high density of unmatching Otto® Wildlife deer carcass records is found on Highway 16 between Topley and Vanderhoof. Triangles and circles indicate unmatching and matching records, respectively (MapMaker.com, 2018).

Topley and Vanderhoof – there were 37 unmatched records and none of deer. Similarly, there were no matching records of 10 deer carcasses on Highway 97 between Cache Creek and Hope. Multiple stretches of highways with clustered deer carcasses were identified: Highway 16 from Sinkut Falls Road to Vanderhoof (0.84 deer/km), Highway 97 between Chetwynd and Taylor (0.83 deer/km), and Highway 97 between Quesnel and Clinton (0.46 deer/km) in the northern most parts of the province. The average matching rate of Otto® Wildlife and WARS records for both species ranged from 13 to 50% (Tables 4 and 5).

DISCUSSION

Our data indicate that the majority of Otto® Wildlife moose (80–90%) and deer carcass records (73–85%) had no matching WARS record, with the relative level of discrepancy dependent on our sorting criteria (days and km separating carcass records). The greater than expected proportion of unmatched records can be partially explained by carcasses removed by other agencies (e.g., Ministry of Environment, RCMP), the public (such as trappers for baiting traps), or scavengers. Furthermore, carcasses concealed by snow plowing before the animal was recorded by a maintenance contractor would influence both availability and matching frequency. Conversely, the proportion of WARS records with a matching Otto® Wildlife record was <3% for both moose and deer; albeit, a low percentage was not unexpected since buses travel stretches of highway only once or less daily, whereas maintenance contractors patrol the same roads several times daily, every day of the week.

If maintenance contractors use the LKI as intended to record carcass locations in WARS, then S1 should be a sufficient criterion, allowing for a spatial recording error of ~1 km on either side of the carcass. Depending on the highway classification, a carcass reported to, or detected by highway maintenance contractors must be removed as soon as possible or within 3 days (Hesse and Rea 2016). Almost all Otto® Wildlife records collected for this study were on primary highways (BC MOTI 2018a), so presumably most carcasses would be removed quickly. Therefore, a 5-day separation (T5) between matching records is a generous matching criterion, and a 3-day separation (T3) should be sufficient assuming protocols are followed. Nevertheless, only 20% of moose and 27% of deer carcasses in Otto® Wildlife were classified as matching with the most relaxed sorting criteria (S5T5). These large discrepancies are unexplained and require further study.

We found that WVCs with moose and deer are most likely to occur in fall and winter, similar to findings by ICBC (Rea 2006, O'Keefe and Rea 2012) and BC MOTI (Sielecki 2010). These seasonal peaks in WVCs are similar to those identified in Alaska (Garrett and Conway 1999) and northern Sweden (Neumann et al. 2012).

An unexpected finding was the seasonal relationship in the proportion of matching between the Otto® Wildlife and WARS records. The matching of moose carcasses between the two databases was higher in fall and winter than spring and summer. It is possible that maintenance contractors and bus drivers can more easily distinguish carcasses in fall and winter when the contrast between a dark-bodied moose and the lighter landscape makes a carcass easier to spot. Most carcass matches for deer occurred in spring with fewest in winter. Beyond the limited sample size, a possible explanation is that carcass reporting by maintenance contractors is less of a priority when crews are preoccupied with plowing and salting roads. Further, plowed snow could reduce detection and/or bury deer carcasses and lower the probability of matching.

The probability of an Otto® Wildlife carcass record having a corresponding WARS record was influenced by region as certain areas had very low rates of matching. Highways in British Columbia are maintained by contractors in 28 service areas throughout the province (BC MOTI 2019), which suggests varied efficiency among maintenance contractors at reporting and removal of carcasses, or that predators or some other agent (e.g., conservation officers, trappers, or the general public; Hesse and Rea 2016) may remove carcasses more frequently. Furthermore, the variation in width of road shoulders and highway right-of-ways, ditch depth, and areas which require brush-cutting may also contribute to differences in detection and matching rates.

The GPS-based, Otto® Wildlife system records sightings of live moose and deer that can be mapped and displayed visually (Fig. 4). Unfortunately, we had no basis to compare between the systems because WARS does not provide these data, but encourage mapping of similar data for mitigation planning. Even though clusters of live animal locations may not necessarily correspond to locations of potential high WVC risk *per se* (Neumann et al. 2012), these data are useful to road safety planners to

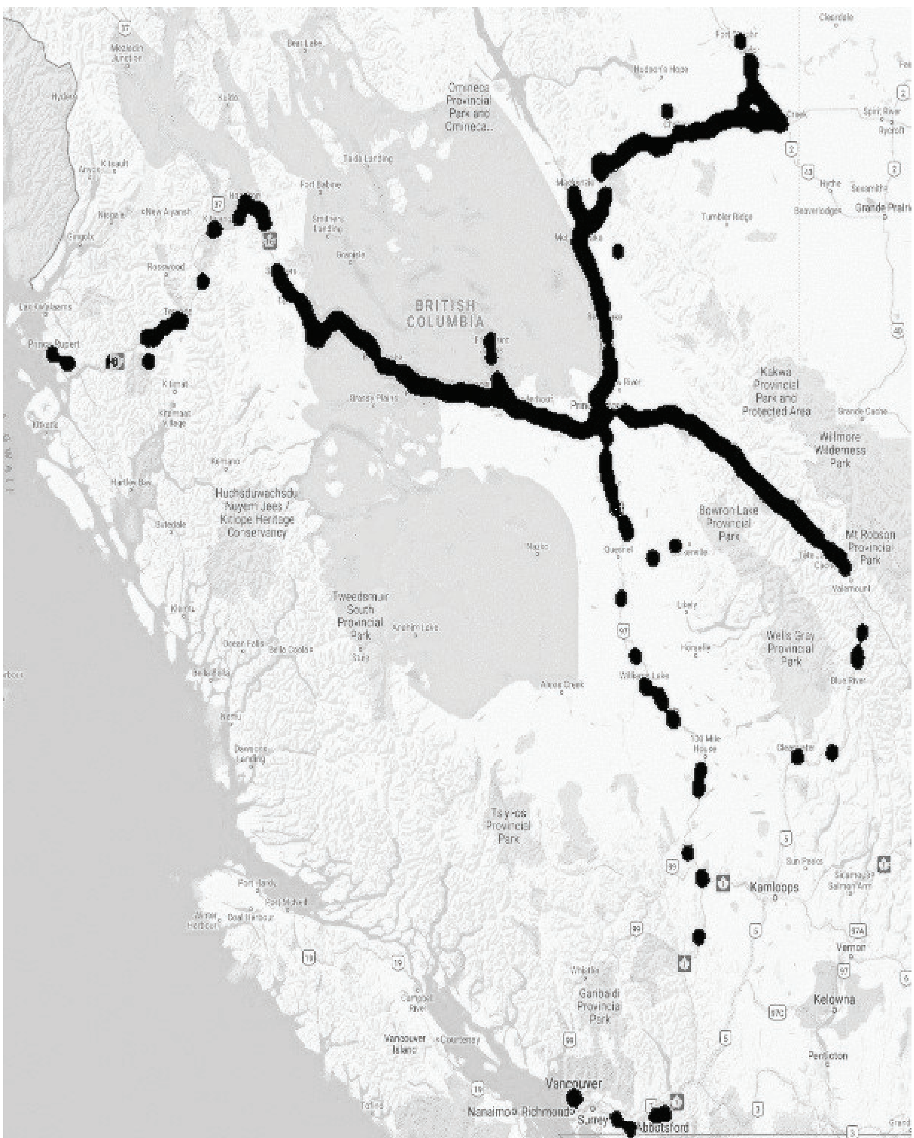

Fig. 4. Map of study area in BC showing live moose sightings recorded by Northern Health Authority bus drivers during the study period (MapMaker.com, 2018).

determine what engineering or environmental factors might explain differences between highway segments with and without WVCs.

Another limitation was the higher probability of observing carcasses with the Otto® Wildlife devices in daylight hours. Northern Health buses operate on set weekly schedules, mainly between 0630 and 2100 hr (Northern Health Connections 2018), whereas highway maintenance contractors are required to remove carcasses all hours of the day. For example, if a bus departs in the morning from a northern centre en route to southern British Columbia, drivers are likely to observe and record MVCs from the previous night (most collisions are nocturnal) near the bus's point of origin; conversely, maintenance contractors would likely have removed carcasses as the bus nears its terminus farther south. It would be useful to collect Otto® Wildlife records 24 h daily and incorporate daily and random route start-times (Hesse et al. 2010).

In some cases, Northern Health bus drivers may have pressed Otto® Wildlife buttons too early or too late to pinpoint a carcass location or missed carcasses; both would increase the occurrence of unmatched records. Although enthusiasm was high when this project launched, it is possible that drivers became less keen on spotting and recording carcasses as the novelty of the project diminished, as occurred during an earlier pilot study (Hesse et al. 2010). It should be noted that most maintenance contractors are trained to "keep an eye out for carcasses" while bus drivers understandably may not have carcasses as their primary search image. Having bus drivers ride with maintenance contractors (and vice versa) could provide for a standardized carcass-spotting protocol and reduce possible biases.

As discussed by Hesse et al. (2010), several modifications could increase the ease of utility of the Otto® Wildlife device. For instance, bigger buttons with different textures for different species would allow drivers to locate the desired button more quickly, increasing the locational accuracy of records. A button to erase the last keystroke would allow drivers to quickly and easily correct entry mistakes, and additional buttons to record animal behaviour might provide unique and valuable data (Hesse et al. 2010).

The use of a smartphone application like that developed in Alberta (Alberta Ministry of Transportation 2017) would help update the WVC record-keeping system in British Columbia. A smartphone application can be easily designed to utilize GPS services and capture the latitude/longitude of collision locations, eliminating the need to reference carcass locations to established roadside landmarks in the LKI system. Not only would a GPS-based record-keeping system facilitate more accurate locations, it could also provide supplementary data including photos and videos if combined with dash-cam technology.

In summary, data from the Otto® Wildlife units provided for a useful comparison of WVCs collected with the traditional WARS system. While temporal and spatial patterns between moose and deer-vehicle collisions were mostly similar for the two systems as expected, matching of WVC data was low. Overall and as expected, more WVCs were recorded with WARS, but many unique carcasses were recorded with the Otto® Wildlife system. We recommend the use of GPS-enabled data collection devices by highway maintenance contractors to provide accurate location data for moose and deer WVCs to promote road safety for motorists and wildlife alike.

POSTSCRIPT: In 2018, the British Columbia Ministry of Transportation and

Infrastructure began the staged rollout of a new policy that mandates the use of GPS technology by all highway maintenance contractors in all Service Areas for the purposes of collecting more accurate WARS data; all carcasses will be identified with a GPS location by 2023.

ACKNOWLEDGEMENTS

We thank Dr. D. Bowering, the Northern Health Authority the Ministry of Transportation and Infrastructure, and Diversified Transportation for partnering with us and installing the Otto® Wildlife devices in their buses. We especially thank the drivers who eagerly worked with us to collect these data. We would like to thank S. Emmons, J. Svendson, and S. O'Keefe for helping with logistics and managing the data during the project and F. Franczk with PERSENTECH Industries for working with us to design the Otto® Wildlife. We thank L. Sielecki for a review of a previous draft of this manuscript. Lastly, we thank our two reviewers for valuable recommendations that led to improvements on an earlier draft of our manuscript.

REFERENCES

Alberta Ministry of Transportation. 2017. Alberta Wildlife Watch Program. <http://www.transportation.alberta.ca/Content/docType253/Production/AlbertaWildlifeWatchProgramPlan.pdf.> (accessed January 2019).

British Columbia Ministry of Transportation and Infrastructure. 2018a. Highway Classification. <https://www2.gov.bc.ca/gov/content/transportation/transportationinfrastructure/transportation-planning/highway-classification.> (accessed March 2019).

_____. 2018b. Landmark Kilometre Inventory July 2018 Version (201807). <https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/engineering-standards-guidelines/landmark-kilometre-inventory.> (accessed March 2019).

_____. 2019. Highway Maintenance. <https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/contracting-to-transportation/highway-bridge-maintenance/highway-maintenance.> (accessed August 2019).

Cadsand, B., D. C. Heard, J. Courtier, A. Batho, and G. S. Watts. 2013. Moose density and composition in the southern Omineca Region, winter 2011–2012. Regional Report for the Ministry of Forest, Lands, and Natural Resource Operations. 35p.

Child, K. N. 1992. Moose Management in the Omineca Sub-region. *In* D. F. Hatler, editor. Proceedings of the 1991 Moose Harvest Management Workshop, November 5–7, 1991. Kamloops, British Columbia. Wildlife Branch, British Columbia Environment, Victoria, British Columbia, Canada.

Garrett, L. C., and G. A. Conway. 1999. Characteristics of moose-vehicle collisions in Anchorage, Alaska, 1991–1995. Journal of Safety Research 30: 219–223. doi: 10.1016/S0022-4375(99)00017-1

Heard, D., S. Barry, G. Watts, and K. Child. 1997. Fertility of female moose (*Alces alces*) in relation to age and body composition. Alces 33: 165–176.

Hesse, G., and R. V. Rea. 2016. Quantifying wildlife vehicle underreporting on northern British Columbia highways 2004–2013. Report prepared for the British Columbia Ministry of Transportation and Infrastructure, Northern Region, Prince George, British Columbia, Canada.

_____, _____, N. Klassen, S. Emmons, and D. Dickson. 2010. Evaluating the Potential of the Otto® Wildlife GPS Device to Record Roadside Moose and Deer Locations for Use in Wildlife Vehicle Collision Mitigation Planning. Wildlife Biology in Practice. 6: 1–13. doi: 10.2461/wbp.2010.6.1

Huijser, M. P., J. Fuller, M. E. Wagner, A. Hardy, and A. P. Clevenger. 2007. Animal-Vehicle Collision Data Collection: A Synthesis of Highway Practice. National Cooperative Highway Research Program (NCHRP) Synthesis 370. Transportation Research Board, Washington, D. C., USA.

ICBC. 2018. Quick Statistics for the Media Manual. <https://www.icbc.com/about-icbc/newsroom/Documents/crashes-involving.pdf.> (accessed January 2020).

MapMaker.com. 2018. MapMaker. <https://www.darrinward.com/lat-long/.> (accessed January 2018).

Meidinger, D., and J. Pojar. 1991. Ecosystems of British Columbia. Special Report No. 6. Ministry of Forests Research Branch, Victoria, British Columbia, Canada.

Neumann, W., G. Ericsson, H. Dettki, N. Bunnefield, N. S. Keuler, D. P. Helmers and C. Radeloff. 2012. Difference in spatiotemporal patterns of wildlife road-crossings and wildlife-vehicle collisions. Biological Conservation 145: 70–78. doi: 10.1016/j.biocon.2011.10.011

Northern Health Connections. 2018. Northern Health Connections Route Schedule. <https://nhconnections.ca/Portals/12/Documents/Bus-Schedule-NH-Connections.pdf.> (accessed January 2019).

O'keefe, S., and R. V. Rea. 2012. Evaluating ICBC Animal–Vehicle Crash Statistics (2006–2010) for Purposes of Collision Mitigation in Northern British Columbia. Report for the Insurance Corporation of British Columbia, North Vancouver, Canada.

Rea, R. V. 2006. Elucidating temporal and species-specific distinctions in patterns of animal-vehicle collisions in various communities and regions of northern British Columbia. In Using Collision Data, GPS Technology and Expert Opinion to Develop Strategic Countermeasures Recommendations for Reducing Animal–Vehicle Collisions in Northern British Columbia. Research Report, Road Health-University Wildlife Collision Mitigation Research Team, Prince George, British Columbia, Canada.

Sielecki, L. E. 2010. WARS 1988–2007: Wildlife Accident Reporting and Mitigation in British Columbia: Special Annual Report. Environmental Management Section, Engineering Branch, British Columbia Ministry of Transportation and Infrastructure, Victoria, British Columbia, Canada. <https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/engineering-standards-guidelines/environmental-management/wildlife-management/wildlife-accident-reporting-system/wars-1988-2007.> (accessed January 2018).