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Review

Systematic review of equids and telemetry collars: implications for deployment and reporting

Jacob D. Hennig[A,D], *J. Derek Scasta*[A], *Jeffrey L. Beck*[A], *Kathryn A. Schoenecker*[B] and *Sarah R. B. King*[C]

[A]Department of Ecosystem Science and Management, University of Wyoming, Laramie, WY 82071, USA.
[B]United States Geological Survey, Fort Collins Science Center, Fort Collins, CO 80526, USA.
[C]Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523, USA.
[D]Corresponding author. Email: jacobhennig@gmail.com

Abstract. Data from animals equipped with global positioning system collars have advanced our understanding of vertebrates, but this technology has rarely been employed to study feral equids. Hesitation to equip feral equids with telemetry collars in the USA can often be attributed to safety concerns stemming from one study from the 1980s, where injuries were sustained by feral horses (*Equus ferus caballus*) equipped with radio-collars. Improvements in collar design over the ensuing quarter-century may have decreased risk of collar-related complications; however, telemetry-based studies on feral equids continue to be limited. In the present review, studies from wild and feral equids worldwide were systematically reviewed to better understand the mortality and injury risk in application of telemetry collars to equids. Our goals were to: (1) report the number of individual equids fitted with telemetry collars (1979–2017); and (2) document the number of individual equids that reportedly died or suffered injuries from collars or other sources. A comparative review of elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*) was also conducted to evaluate the relative risk of collar-related complications among equids and routinely collared North American ungulates. In total, 1089 wild and feral telemetered equids were identified across 48 studies. Of these, 87 (8.0%) were reported to have died, with only one (0.09%) mortality attributable to a collar. Comparatively, 23.0% (1095) of 4761 elk, mule deer and pronghorn fitted with telemetry collars were found to have died in the same number of studies, though no mortalities were reported to be related to the collar. Although wild and feral equids did not experience increased natural mortality compared with the other ungulates, studies have not provided sufficient information to assess relative risk of collar-related complications. Explicit reporting and discussion of telemetry collar impacts in future publications of all animal species are recommended, especially equids, to improve understanding of how telemetry collars can affect study individuals.

Additional keywords: conservation, feral species, mortality, ungulates, wildlife management.

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Introduction

In modern wild animal research, global positioning system (GPS) technology is routinely implemented to collect spatiotemporally robust data that can be used to answer questions that could not easily be addressed before its development (Cagnacci *et al.* 2010). By employing GPS technology, we have better understanding of how animals respond to anthropogenic features (Panzacchi *et al.* 2013; Sawyer *et al.* 2013), increased knowledge of habitat selection (Leclerc *et al.* 2016; Valls-Fox *et al.* 2018) and improved information on predator–prey dynamics (Hebblewhite *et al.* 2005; DeMars and Boutin 2017). In turn, such information has been imperative for informing successful conservation efforts and evaluating management actions (Wydeven *et al.* 2009; Sawyer *et al.* 2012).

Wild and feral equids are iconic megafauna that elicit strong conservation and management concern worldwide. GPS technology has been instrumental in improving the conservation and management of multiple wild equid species. Data from individuals equipped with GPS collars have elucidated movement barriers for Asiatic wild ass (*Equus hemionus*; Ito *et al.* 2013), uncovered unknown migrations of plains zebra (*E. quagga*; Naidoo *et al.* 2016), revealed that core foraging areas of Grevy's zebra (*E. grevyi*) fell outside of protected ranges (Levikov 2014) and found that desert reintroduction sites represent marginal habitat for the previously extinct-in-the-wild Przewalski's horse (*E. ferus przewalskii*; Kaczensky *et al.* 2008). Conversely, GPS technology has rarely been deployed to study feral horses or burros (*E. asinus*), particularly in the USA, with safety issues cited as a concern (Collins *et al.* 2014; Schoenecker *et al.* 2020).

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The attachment of telemetry transmitters can negatively affect individuals of any species (see Krausman *et al.* 2004; Walker *et al.* 2012; Severson *et al.* 2019). For large, terrestrial mammals, transmitters are often attached to an individual via a neck collar. Equids have been posited to face increased safety risk from neck collars due to their tapering neck shape, which can make for a difficult proper fit (Collins *et al.* 2014; Schoenecker *et al.* 2020). These safety concerns are most apparent in the USA, where they led to a moratorium on telemetry collar use (see Schoenecker *et al.* 2020) on feral horses and burros protected and managed by the federal government under the *Wild Free Roaming Horses and Burros Act* of 1971 (Public Law 92–195, http://www.gpo.gov/fdsys/pkg/STATUTE-85/pdf/STATUTE-85-Pg649.pdf, accessed 24 March 2019). Recent rapid population growth has led to increased scrutiny of feral horse and burro management amid concerns about effects they may have on native flora and fauna (Scasta *et al.* 2018). Horse-occupied sites exhibit altered vegetation composition and structure, different faunal communities, and decreased soil integrity compared with similar sites where horses were removed or excluded (Beever and Brussard 2000; Zalba and Cozzani 2004; Beever and Herrick 2006; Davies and Boyd 2019). Further, horses can contribute to the spread of invasive species such as cheatgrass (*Bromus tectorum*; King *et al.* 2019), and negatively influence water use by co-occurring native species (Hall *et al.* 2016; Gooch *et al.* 2017). In addition, managers have little, or outdated, information on the natural history of horses and burros, such as home-range sizes, daily movement distances and habitat selection. Data from GPS collars would undoubtedly improve our understanding of these populations, yet safety concerns still cause hesitation to employ this technology.

Complications resulting from feral horse radio-collar studies in the late-1980s are the primary cause of such concerns (NRC 1991). Issues from this Nevada, USA study were primarily attributed to collar design, collar fit and selection of immature study individuals – all aspects of collar research that have improved over time. Specifically, collars were made of 10.2-cm wide, rigid belting material, which made fine adjustments difficult, and nearly all individuals aged 2–5 years experienced collar complications (NRC 1991). Specific improvements have been made in collar design and animal-care-and-use guidelines over the past quarter-century through the integration of better collar material and lighter hardware (such as batteries and GPS units). Furthermore, a recent pilot study illustrated that with proper collar design and fit, GPS collars can be safely used on mature, free-roaming horses (Collins *et al.* 2014). Nonetheless, the use of GPS collars on federally protected feral equids in the USA remains a contentious issue that has restricted deployment by researchers to improve ecological understanding and decision making.

To better understand if telemetry collars impose increased risk to equids relative to other wild ungulates, we conducted two literature reviews. We first performed a systematic review of all literature studies reporting telemetry collar data from wild and feral equids from 1979 to 2017. Our goals for this review were to: (1) report the number of individual equids fitted with telemetry collars; and (2) document the number of individual equids that reportedly died or suffered injuries from collars or other sources. We then conducted a companion abbreviated review with an equivalent number of studies and during the same time period to our equid systematic review to evaluate the relative risk of collar-related complications between equids and routinely collared North American ungulates – elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*). We chose these species because all have been frequently studied with telemetry collars, and each overlap in range with feral equids in western North America (Scasta *et al.* 2016).

Table 1. Search terms used for the systematic review of wild and feral equid studies utilising telemetry collars globally to determine safety and application

Equid term	Technology term
Ass	Collar
Brumby	GPS
Burro	Global positioning system
Donkey	VHF
Equid	Very high frequency
Equus	
Grevy's	
Horse	
Khulan	
Kiang	
Konik	
Mustang	
Onager	
Pony	
Przewalski's	
Takhi	
Zebra	

Table 2. Inclusion criteria for wild and feral equid studies utilising telemetry collars in a global systematic review to determine safety and application

Inclusion category	Criteria
Animals	Any species of the genus *Equus* that was either wild or kept in an extensively managed pasture or enclosure
Technology	Global positional system or very high frequency telemetry device affixed to a neck collar
Temporal range	1970–2017
Spatial range	Global
Qualifying criteria	We considered studies explicitly employing telemetry tracking devices affixed to a neck collar. We did not include studies that did not report telemetry data, such as papers focussed on the capture of animals for subsequent collaring.

Methods

We followed systematic review guidelines (Centre for Evidence-Based Conservation 2013) to ensure transparency and repeatability for our global equid review. We defined *a priori* systematic search terms (Table 1) and review criteria (Table 2) for our review and performed searches using Web of Science and Google Scholar online databases. We assessed each study meeting the review criteria and extracted the following information: (1) study location; (2) telemetry type; (3) number of collared individuals; and (4) number and causes of mortalities and injuries. We included grey literature (reports, theses) because its exclusion would have resulted in the loss of valuable information, particularly as it relates to early collaring research on equids in the USA that have never appeared in the peer-reviewed literature (including NRC 1991). While conducting our review, it became apparent that in several instances a single telemetry dataset was the basis for publication of multiple papers. When such situations were identified, we reconciled results to avoid duplication and redundancy in our reported results.

Following our systematic global equid review, we conducted a companion review of studies reporting data from telemetry-collared elk, mule deer, and pronghorn in North America using the Google Scholar database. More than 14 000 studies were found in the initial screening process; thus, we determined that it would be unfeasible to conduct this companion review as an exhaustive review of all studies. We therefore applied analogous search terms (elk OR mule deer OR pronghorn AND collar) but only reviewed 48 studies that corresponded to the number of studies reporting unique telemetry data from equids. We used studies matching the same publication date range and stratification as the systematic global equid review studies (four studies from 1979–89, three from 1990–99, and matching years from 1999–2017), and the same number of peer-reviewed articles, reports and theses per year. To accomplish this without imposing bias, we chose which studies to review based on a random number generator. If the resulting study did not meet an appropriate year*publication type, another random study was selected until these criteria were met. We reviewed each study to extract data for the number of collared individuals, along with the number and causes of reported mortalities and injuries occurring during the studies.

Results

Equids

We identified 169 relevant results during our equid review from the screening of titles and abstracts, of which 83 ultimately met our review criteria (Table S1, available as Supplementary material to this paper). Of these 83 studies, we identified 48 containing unique telemetry datasets (Table 3). Collared equids included four wild and two feral species spanning 18 countries and five continents (Fig. 1). Species fitted with collars were Asiatic wild ass, Przewalski's horse, plains zebra, Grevy's zebra, feral horse and feral burro (Table S1). We found no sources reporting use of telemetry collars on African wild ass (*E. africanus*), kiang (*E. kiang*), nor mountain zebra (*E. zebra*).

Across all equid species, 1089 individuals have been fitted with telemetry collars. Of these individuals, 83 (7.6%) were reported as mortalities during studies (Fig. 2). Most known mortality causes were natural (old age or disease; 75.9%), followed by depredation (7.2%), hunting or poaching (3.6%) and capture-related mortalities (3.6%). Only one mortality (0.09%) was explicitly stated to be caused by the telemetry collar (NRC 1991). Four causes of mortalities were unknown (4.8%), with no causes reported for an additional three deaths (3.6%). Overall, 10 studies (20.8% studies) reported at least a single mortality (Table 3), with only one study reporting a death related to a telemetry collar.

Injuries attributed to fit and mass of collars were described in four studies (8.3% of studies; NRC 1991; Brooks *et al.* 2008; Hampson *et al.* 2011; Fortini 2015), involving 87 individuals (8.0% of collared individuals). Seventy-seven (88.5%) of these injuries were observed in one study in Nevada, USA conducted between 1985 and 1990 (NRC 1991). Of 336 very high frequency (VHF) collars fitted to feral horses in this study in Nevada, 42 were attached too tightly or became too tight over time, resulting in lacerations and infections. Conversely, 35 collars were fitted too loosely or became too loose over time, causing them to slip up over the horses' ears, resulting in cuts, sores and infections. In addition, reported injuries were explicitly attributed to the placement of collars on immature horses, and the rigid and broad material that was used for the collar (see pages 26–28 in NRC 1991).

In terms of effects that did not cause injury or death, collar weight may have affected the foraging behaviour of five plains zebra (Brooks *et al.* 2008). Brooks *et al.* (2008) fitted eight collars from two different manufacturers to zebra. Subsequently, the five individuals fitted with the heavier collar type moved half as much when foraging compared with the three individuals wearing lighter collars. Additionally, five feral horses in two studies were reported to have reduced body condition after being affixed with a collar, though causes were unknown (Hampson *et al.* 2011; Fortini 2015).

North American ungulates

Compared with equids, elk, mule deer and pronghorn had higher reported mortality across studies. Twenty-seven of 48 (56.3%) studies reviewed (Table 4) reported mortalities. In these studies, 4761 individual elk, mule deer or pronghorn were fitted with telemetry collars; of these, 1095 (23.0%) were reported as mortalities (Fig. 2). Of those reported, most causes of mortality were either not stated (27.2%) or unknown (18.9%). Hunting or poaching were the most frequent known causes of death (21.5%), followed by depredation (14.8%), natural causes (9.2%), vehicle collisions (5.4%), capture-related mortality (2.6%) and other causes (0.4%). No mortalities were explicitly stated to be collar related. Likewise, no studies mentioned any collar-related injuries or other collar effects.

Discussion

Our review found that equids have been fitted with telemetry collars less frequently than the three species of North American ungulates in this review, both in number of studies and number of individuals collared per study. Although safety concerns have prevented telemetry collar use on federally protected feral equids in the USA, relatively vulnerable population sizes, difficulty of capture and limited budgets are possible reasons for infrequent use on other equid populations. Nonetheless, vulnerable equid species have been fitted with GPS collars, suggesting that safety is either not perceived as an issue for these equids, or the need for collecting spatial data outweighs any potential safety concerns. Different perceptions of zebra, for example, being considered wildlife, compared with feral horses

Table 3. Studies possessing unique telemetry data and meeting *a priori* inclusion criteria in a global systematic review of wild and feral equid studies utilising telemetry collars (1979–2017)

Numbers in parentheses correspond to mortalities and injuries directly attributed to a telemetry collar. GPS, global positioning system; VHF, very high frequency; NA, not applicable (mortalities or injuries were not reported)

Reference	Continent	Collar type	No. collars	Publication type	Mortalities reported	Injuries reported
Feral horse (*Equus caballus*)						
Berman 1991	Australia	VHF	5	Thesis	NA	NA
Hampson *et al.* 2010*a*	Australia	GPS	3	Peer-reviewed	0	0
Hampson *et al.* 2010*b*	Australia	GPS	12	Peer-reviewed	0	0
Hampson *et al.* 2011	Australia	GPS	6	Peer-reviewed	3	1 (1)
Fortini 2015	Europe	GPS	6	Thesis	0	4 (4)
Jodowska *et al.* 2015	Europe	GPS	1	Peer-reviewed	NA	NA
Köhler *et al.* 2016	Europe	GPS	1	Peer-reviewed	0	NA
Popp and Scheibe 2014	Europe	VHF	1	Peer-reviewed	NA	NA
Radoi *et al.* 2015	Europe	GPS	32	Peer-reviewed	NA	NA
van Hoesel and van der Werff 2011	Europe	GPS	2	Thesis	0	NA
Collins *et al.* 2014	North America	GPS	28	Peer-reviewed	0	0
Ehsan *et al.* 2012	North America	GPS	6	Peer-reviewed	NA	NA
Ganskopp and Vavra 1986	North America	VHF	11	Peer-reviewed	NA	NA
Girard *et al.* 2013	North America	GPS	4	Peer-reviewed	NA	NA
Goodloe *et al.* 2000	North America	VHF	10	Peer-reviewed	NA	NA
Leverkus 2015	North America	GPS	13	Thesis	NA	NA
National Research Council 1991	North America	VHF	336	Report	63 (1)	77 (77)
Siniff *et al.* 1986	North America	VHF	169	Peer-reviewed	4	NA
Zervanos and Keiper 1979	North America	VHF	10	Report	NA	NA
Przewalski's horse (*E. f. przewalskii*)						
Kaczensky and Huber 2010	Asia	GPS	1	Peer-reviewed	0	0
Kaczensky *et al.* 2008	Asia	GPS	9	Peer-reviewed	1	NA
Kaczensky *et al.* 2010*b*	Asia	GPS	5	Peer-reviewed	0	NA
Lugauer 2010	Asia	GPS	2	Thesis	NA	NA
Asiatic wild ass (*E. hemionus*)						
Giotto *et al.* 2015	Asia	GPS	5	Peer-reviewed	NA	NA
Kaczensky *et al.* 2008	Asia	GPS	7	Peer-reviewed	1	NA
Kaczensky *et al.* 2010*a*	Asia	GPS	16	Peer-reviewed	0	NA
Kaczensky *et al.* 2010*b*	Asia	GPS	10	Peer-reviewed	0	NA
Kaczensky *et al.* 2011*a*	Asia	GPS	14	Peer-reviewed	1	NA
Kaczensky *et al.* 2011*b*	Asia	GPS	12	Peer-reviewed	NA	NA
Shah and Qureshi 2007	Asia	VHF	2	Peer-reviewed	NA	NA
World Bank 2006	Asia	GPS	7	Report	1	NA
Feral burro (*E. asinus*)						
Marshal *et al.* 2012	North America	VHF	44	Peer-reviewed	NA	NA
Seegmiller and Ohmart 1981	North America	VHF	7	Peer-reviewed	0	NA
Grevy's zebra (*E. grevyi*)						
Hostens 2009	Africa	GPS	16	Thesis	NA	NA
Levikov 2014	Africa	GPS	26	Thesis	NA	NA
Sundaresan *et al.* 2007	Africa	VHF	6	Peer-reviewed	NA	NA
Wheeler 2013	Africa	GPS	10	Thesis	NA	NA
Younan 2015	Africa	GPS	21	Thesis	NA	NA
Plains zebra (*E. quagga*)						
Barnier *et al.* 2014	Africa	GPS	7	Peer-reviewed	NA	NA
Bartlam-Brooks *et al.* 2011	Africa	GPS	26	Peer-reviewed	2	0
Bradley 2012	Africa	GPS	21	Thesis	4	NA
Brooks 2005	Africa	GPS	25	Thesis	NA	5 (5)
Courbin *et al.* 2016	Africa	GPS	22	Peer-reviewed	NA	NA
Fischhoff *et al.* 2007	Africa	GPS	4	Peer-reviewed	NA	NA
Hopcraft *et al.* 2014	Africa	GPS	13	Peer-reviewed	NA	NA
Kamath *et al.* 2014	Africa	GPS	70	Peer-reviewed	NA	NA
Macandza 2009	Africa	GPS	6	Thesis	NA	NA
Martin and Owen-Smith 2016	Africa	GPS	4	Peer-reviewed	0	0
Naidoo *et al.* 2016	Africa	GPS	8	Peer-reviewed	1	NA
Venter *et al.* 2014	Africa	GPS	7	Peer-reviewed	4	NA

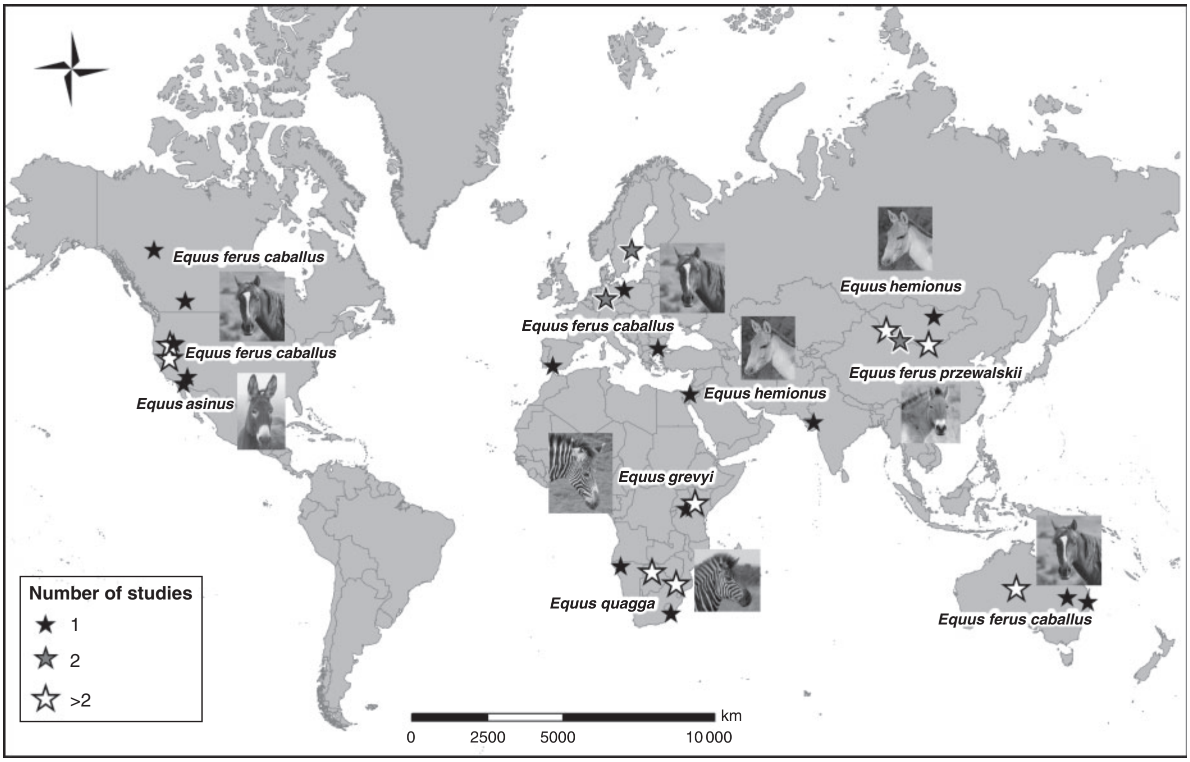

Fig. 1. Locations of all studies reporting data from telemetered wild and feral equids (1979–2017). Also shown are the number of studies from each location, telemetry collar type (very high frequency (VHF) in white, global positioning system (GPS) in black), and the species of equids collared at each location. Some studies occurred at more than one location and/or collared more than one equid species.

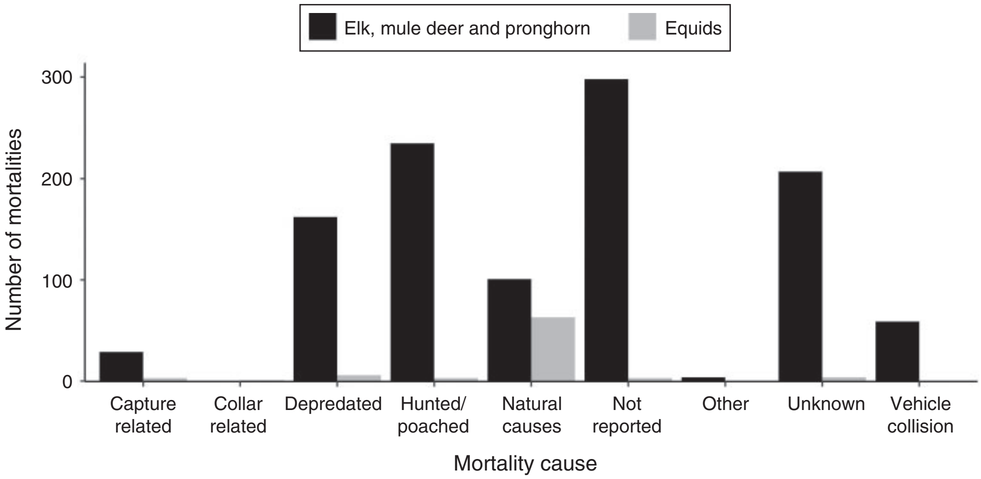

Fig. 2. Number of all telemetry-collared equids, mule deer, elk and pronghorn per mortality cause from reviewed studies utilising telemetry collars (1979–2017).

being domesticated, may also have influenced the relative importance and emotive nature of safety against data collection.

Research of wild and feral equids employing GPS collars has provided important insights into their ecology. The ability to collect relocation data at fine spatiotemporal scales has allowed more accurate estimates of home-range sizes and daily movement distances (e.g. Hampson *et al.* 2010*a*; Girard *et al.* 2013; Levikov 2014). Additionally, the resolution of data obtained from GPS has enhanced understanding of foraging and movement behaviours of equids at unprecedented scales (Kaczensky *et al.* 2011*a*; Owen-Smith *et al.* 2015). Furthermore, by placing GPS collars on multiple species, we better understand

Table 4. All studies reviewed in the comparative search for studies utilising telemetry collars on elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*)

GPS, global positioning system; VHF, very high frequency; NA, not applicable (mortalities or injuries were not reported)

Reference	Country	Collar type	No. collars	Publication type	Mortalities reported
Elk (*Cervus canadensis*)					
Irwin and Peek 1983	USA	VHF	16	Peer-reviewed	NA
Witmer and deCalesta 1985	USA	VHF	6	Peer-reviewed	NA
Biggs *et al.* 1997	USA	GPS	6	Report	2
Petersburg *et al.* 2000	USA	VHF	52	Peer-reviewed	35
DeGroot and Woods 2006	Canada	VHF/GPS	24	Report	1
Sargeant and Oehler 2007	USA	VHF/GPS	175	Peer-reviewed	36
Hebblewhite and Merrill 2007	Canada	VHF/GPS	131	Peer-reviewed	93
Anderson *et al.* 2008	USA	GPS	7	Peer-reviewed	NA
Gower 2009	USA	VHF	115	Thesis	95
Woodside 2010	USA	GPS	10	Thesis	0
Laporte *et al.* 2010	Canada	GPS	22	Peer-reviewed	NA
Smallidge *et al.* 2010	USA	VHF	110	Peer-reviewed	NA
Brook 2010	Canada	VHF/GPS	130	Peer-reviewed	NA
Baasch *et al.* 2010	USA	VHF	21	Peer-reviewed	NA
Biggs *et al.* 2010	USA	GPS	29	Peer-reviewed	NA
Kolada 2011	USA	VHF	10	Thesis	0
Webb *et al.* 2011	USA	VHF/GPS	184	Peer-reviewed	39
Kindall *et al.* 2011	USA	VHF	156	Peer-reviewed	62
Ciuti *et al.* 2012	Canada	GPS	122	Peer-reviewed	25
Starr 2013	USA	GPS	10	Thesis	1
Beck *et al.* 2013	USA	VHF	46	Peer-reviewed	7
Monello *et al.* 2014	USA	VHF	136	Peer-reviewed	29
Pruvot *et al.* 2014	Canada	GPS	168	Peer-reviewed	NA
Buchanan *et al.* 2014	USA	VHF/GPS	76	Peer-reviewed	NA
Roberts 2015	USA	GPS	25	Thesis	3
Smith 2015	USA	GPS	108	Thesis	NA
Mule deer (*Odocoileus hemionus*)					
Springer and Wenger 1981	USA	VHF	23	Report	6
Eberhardt and Cadwell 1985	USA	VHF	17	Peer-reviewed	NA
Relyea *et al.* 1994	USA	VHF	10	Peer-reviewed	NA
Gray 1995	USA	VHF	77	Thesis	24
D'Eon and Serrouya 2005	Canada	GPS	20	Peer-reviewed	NA
Haskell 2007	USA	VHF	303	Thesis	135
Bender *et al.* 2011	USA	VHF	46	Peer-reviewed	22
Kolada 2011	USA	VHF	10	Thesis	1
Silbernagel *et al.* 2011	Canada	GPS	107	Peer-reviewed	NA
McKee 2012	USA	GPS	81	Thesis	17
Schuler *et al.* 2014	USA	GPS	40	Peer-reviewed	2
Northrup *et al.* 2014	USA	GPS	134	Peer-reviewed	NA
Lendrum *et al.* 2014	USA	GPS	100	Peer-reviewed	NA
Freeman 2014	USA	VHF	189	Thesis	NA
Marescot *et al.* 2015	USA	GPS	60	Peer-reviewed	24
Coe *et al.* 2015	USA	GPS	492	Peer-reviewed	162
Mulligan 2015	USA	VHF/GPS	621	Thesis	223
Olson *et al.* 2015	USA	GPS	31	Peer-reviewed	NA
Perez-Solano *et al.* 2016	Mexico	VHF	9	Peer-reviewed	1
Pronghorn (*Antilocapra americana*)					
Kolar 2009	USA	VHF/GPS	218	Thesis	27
Beckmann *et al.* 2012	USA	GPS	125	Peer-reviewed	NA
Jacques *et al.* 2014	USA	VHF	61	Peer-reviewed	NA
Collins 2016	USA	GPS	39	Peer-reviewed	2
Taylor *et al.* 2016	USA	GPS	52	Peer-reviewed	21

how equids partition resources with sympatric species (e.g. Macandza *et al*. 2012*a*, 2012*b*; Owen-Smith and Martin 2015). Better information on all of these topics is sorely needed for improved understanding of how feral equids may impact native flora and fauna and for re-introduced equids in re-wilding or restoration efforts in other countries.

Our review found that the reported mortality rate of collared equids was lower than for collared elk, mule deer and pronghorn in North America. Some of this disparity is due to native ungulates being routinely hunted; however, excluding hunting and poaching mortalities still suggests a higher percentage of ungulates than equids die from other causes (19.0% *v.* 7.3%). A major limitation of our review is that mortalities are not required to be reported by publications and often were not reported unless studies were addressing cause-specific mortalities. Many studies that did report mortalities merely mentioned the number of individuals that died, without indicating what caused these deaths. Furthermore, collars may not be retrieved until well after the mortality has occurred, making it difficult to assign a cause of death (e.g. Taylor *et al.* 2016). Additionally, it is often time and cost-prohibitive to monitor collared animals in the field with enough regularity to identify whether collars have caused injuries to an individual. Many studies employ aircraft to locate individuals or use satellite systems to relay locations, which limits observations of collared individuals after deployment.

Another limitation of our review is that it is difficult to disentangle whether collar complications were a proximate cause of mortality. Injuries or other collar related complications were rarely mentioned in equid studies (4.3% of studies) and completely absent in the ungulate studies we reviewed. We know, however, that collars can cause injuries to ungulates because they caused neck lesions in mule deer and bighorn sheep (*Ovis canadensis*) in California, USA (Krausman *et al.* 2004). The authors of this study stated they contacted the collar manufacturer to apprise them of the complications from their collars so that they could use the information to design a safer collar. Wild ungulates in North America have been widely studied with telemetry collars for the past half-century, therefore safety issues have likely been identified and corrected so that current safety risk is minimal (e.g. Keister *et al.* 1988; Diefenbach *et al.* 2003; Krausman *et al.* 2004; Obermoller *et al.* 2018). Because collars have rarely been used on feral equids, information on improving collar design for these animals is lacking. Without more information, we are unable to show whether equids suffer increased risk of mortality or injury due to telemetry collars compared with other ungulates.

Conclusions

Feral horses are the most abundant equid worldwide (Linnell *et al.* 2016), yet we know little about their spatial ecology compared with several species of threatened, wild equids. GPS technology could be used to collect robust data useful for improving management of feral horses and burros, especially in countries where debate of their management is contentious (e.g. Australia, Canada, USA). Currently, the two federal agencies with authority of equid management in the USA, the United States Department of Interior's Bureau of Land Management and the United States Department of Agriculture's Forest Service have little information on how animals move across political boundaries, how seasonality influences resource selection and movement patterns and how these animals compete for or partition resources with wildlife and livestock species.

In the published literature, discussion of collar-related complications, or lack thereof, is rare. This is not often a goal of studies; thus, it is seemingly extraneous to include, especially given the cost of page charges. Nonetheless, limited understanding of how telemetry collars impact equids hinders their employment on feral equids under highly scrutinised management. Therefore, we encourage published research to explicitly discuss if collars affected study individuals, especially equids, when applicable.

Conflicts of interest

The authors declare no conflicts of interest.

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