UNED Research Journal
Cuadernos de Investigación UNED

LITERATURE REVIEW

Potential ecological effects of the free-roaming horses, *Equus caballus* (Perissodactyla: Equidae) on wild mammals: a review

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Received 27-V-202 • Corrected 01-VI-2021 • Accepted 02-VI-2021
DOI: https://doi.org/10.22458/urj.v13i2.3488

ABSTRACT. Introduction: The horse (*Equus caballus*) is an adaptable large herbivore distributed in a wide range of terrestrial biomes that negatively affects ecosystems around the world. Most research on horse–ecosystem interactions have focused on plants and soils, whereas horse effects on vertebrate species are poorly understanded. **Objective:** To synthesize, at a global scale, the effects of free-roaming horses on wild mammals. **Methods:** We conducted a systematic literature review that included the words "feral horses + competition", "feral horses + interactions", "feral horses + impacts", "feral horses + effects", based on the "Web of Science" internet search engine. **Results:** We located 366 articles , but only 14 peer-reviewed documents described the effects of horses on local wild mammals. Most studies were published in the last decade and were about ecosystems in the United States of America (64%). Most used correlational approaches; experimental studies were rare. The effect of horses on mammals varied significantly, suggesting that changes on habitat structure mostly affects small rodents. Nevertheless, large ungulates had interference competition with the horses. **Conclusion:** We recommend monitoring proxies, for example ungulates and rodents, to determine if the presence of horses in protected areas affects conservation.

Keywords: Wildlife, habitat, ungulates, rodents, horses, grazing.

RESUMEN. "Efectos ecológicos potenciales de los caballos silvestres, *Equus caballus* (Perissodactyla: Equidae), en mamíferos silvestres: revisión". **Introducción:** El caballo (*Equus caballus*) es un herbívoro grande y adaptable, distribuido en una amplia gama de biomas terrestres, que afecta negativamente ecosistemas en todo el mundo. La mayoría de las investigaciones sobre las interacciones entre el ecosistema y el caballo se han centrado en plantas y suelos, mientras que sus efectos sobre otros vertebrados no se comprenden bien. **Objetivo:** Sintetizar, a nivel mundial, los efectos de los caballos sobre los mamíferos silvestres. **Métodos:** Hicimos una revisión sistemática de literatura con las palabras "feral horses + competition", "Feral horses + interactions", "feral horses + impacts", "feral horses + effects", en el motor de búsqueda "Web of Science". **Resultados:** Encontramos 366 artículos, pero solo 14 revisados por pares. La mayoría de la última década y en Estados Unidos de América (64%). Los enfoques más utilizados fueron de correlación, siendo escasos los experimentales. El efecto varió significativamente, sugiriendo que los cambios en la estructura del hábitat afectan principalmente a los roedores pequeños. Los ungulados compiten por interferencia con los caballos. **Conclusión:** Recomendamos monitorear indicadores, por ejemplo ungulados y roedores, para determinar si la presencia de caballos en áreas protegidas afecta la conservación.

Palabras clave: Vida silvestre, hábitat, ungulados, roedores, caballos, pastoreo.

The horse (*Equus caballus*) is an adaptable herbivore distributed on several continents, it is found in a variety of terrestrial biomes, and negatively affects ecosystems around the world (Eldridge et al., 2020). Factors such as having few predators, high survival, environmental tolerance,

mobility and dispersal ability, as well as high resistance to diseases, make horses dominant over many native species (Scorolli, 2016).

There is scarce literature on the effects of feral horses on vegetation, soils, hydrology, and wildlife (Baur et al., 2017; Beever & Brussard, 2000; Beever & Herrick, 2006; Boyd et al., 2017; Cherubin et al., 2019; De Villalobos & Schwerdt, 2017; Robertson et al., 2019). Available studies have synthesized information of its impact on ecosystems at regional or local scale; for example, Nimmo and Miller (2007) reviewed the ecological and human dimensions of horse management in Australia; Driscoll et al. (2019) synthesized the impact of wild horses in the Kosciuszko National Park, also in Australia; Davies and Boyd (2019) analyzed the ecological effects of horse grazing on the native grasslands of North America; and Scorolli (2016, 2018) compiled and analyzed information on the ecological consequences and management of feral horses in Argentina. Recently, Eldridge et al. (2020) carried out a global scale meta-analysis of potential impacts of feral horses on the structure, functionality, and composition of ecosystems. Most information is focused on plants and soils, whereas the effects of horses on native wildlife vary from one study to another, focusing primarily on iconic species. For this reason, previous authors did not assess the effects of horses on specific taxa, for example, on mammals. Therefore, it is necessary to summarize the effect of horses on mammal species to inform and improve decision-making.

Horses can affect wildlife directly, by competing for resources, or indirectly, by altering structural components of the habitat, such as vegetation and soil (Cherubin et al., 2019; Eldridge et al., 2019; Gooch et al., 2017; Hall et al., 2016; Perry et al., 2015). Information about this topic would help with the conservation of wildlife associated with horse grazing sites. We conducted a global-scale literature review to summarize the effects of horses on wild mammals. Our goal was to identify the geographic distribution of studies, determine the methodological approaches and variables most commonly used to evaluate the effects of horses presence on wild mammals, and to classify these effects as “direct” or “indirect”.

MATERIALS AND METHODS

To provide an overview of the effect of the presence of horses on wild mammals, we conducted a systematic literature review using the search engine "*Web of Science*" and the following search terms: "*feral horses + competition*", "*feral horses + interactions*", "*feral horses + impacts*", "*feral horses + effects*". The systematic search was temporally delimited to 2020, only selecting sources from peer-reviewed publications. We did not include master's and doctoral dissertations, unofficial reports, or articles without peer review. We manually filtered the results to exclude articles not related to the topic, such those that dealt with relationships between horses and plants, invertebrates, or domestic mammals. Subsequently we classified the documents according to: 1) year of publication, 2) country, 3) taxonomic group, 4) type of study, 5) responses evaluated, and 6) type of effect. Taxonomic groups were clustered in three categories; carnivores, rodents, and ungulates. This classification was the most appropriate due to the different taxonomic levels (species or communities) evaluated in the reviewed documents. To sort the documents, we adapted the categories used by Schieltz and Rubenstein (2016), who reviewed the effects of cattle grazing on wildlife and classified the studies into three categories (Table 1). We categorized responses evaluated in each study according to changes in abundance, behavior, daily activity pattern, detectability, habitat use, occupancy, occurrence, and species richness. Studies reporting more than one taxonomic group, method, and response were analyzed independently. In order to classify the type of effects, we adapted an *a priori* model proposed by Eldridge et al. (2019), considering direct effects as responses derived from horse presence, whereas indirect effects were secondary changes in structural components of habitat (e.g., soil, vegetation) derived from horse presence. To

determine a possible difference in the effect of horses between taxonomic groups, we used a chi-square test to compare the observed distribution. Statistical analyses were performed with statistical software R version 3.6.0 (R Development Core Team, 2019), using a statistical significance of $p < 0.05$.

TABLE 1

Study types used to classify the documents about effects of horses on wild mammals. Adapted from Schieltz and Rubenstein (2016)

Type of study	Description
Controlled experiment	The authors created treatments or manipulated variables to test the effect of horse grazing.
Natural experiment	The authors used some type of variation in the grazing intensity of the horses in the landscape as treatments to specifically examine the effect of this factor.
Correlational study	The authors use an existing gradient or variation in some grazing factors, often in combination with other environmental covariates.

RESULTS

In total, 366 articles were found, but only 14 described effects of horse presence on wild mammals. We observed an increasing number of publications, where three (22%) of the 14 documents evaluated, were published between 1985 and 2000, two (14%) between 2001–2010, and nine (64%) during the last decade (2011–2020) (Appendix 1). The reviewed studies were aggregated in three countries: nine in the United States (64%), four in Australia (29%), and one in India (7%) (Fig. 1). Eight studies were focussed on ungulates (57%), seven on rodents (50%), and only one on carnivores (3%).

The 14 articles evaluated showed most studies were correlational (n = 72%), followed by the natural experiment (n = 21%) and controlled experiments (n = 7%) (Appendix 2). Responses evaluated were highly variable between taxonomic groups. The assessed response variable most used was abundance (n = 9), followed activity patterns (n = 6), species richness (n = 5), behavior (n = 4), habitat use (n = 3), detectability (n = 1), occupation (n = 1) and occurrence (n = 1) (Fig. 2.).

Significant differences were observed between the presence of horses with regard the mammal sub-group studied ($X^2 = 12.34$, $p < 0.05$). The presence of horses reported direct effects on carnivores (n = 1) and ungulates (n = 8), whereas the effect on rodents reported was mostly indirect (n = 6). The only study that evaluated the effect of horse presence on carnivores determined a direct effect on daily activity patterns; at waterholes where the horses frequently visit, the records of native species was significantly lower compared to bodies of water where horses were excluded. The presence of horses was associated with soil compaction, changes in vegetation such as lower species richness, lower percentage of coverage and, lower height, and abundance of grasses and shrubs. These alterations in the structural components of the habitat caused changes in the number of refugees, abundance, activity, use of habitat, occupation, and occurrence of rodents. One study determined the direct effect of the presence of horses on the richness, abundance, and daily activity of rodents in bodies of water, these being higher in sites excluding horses. For studies analyzing the effect of horses on ungulates, water was the most limiting factor on visits, time spent at sites decreased with horse presence. Species richness and abundance showed a decrease in sites frequently visited by horses compared to sites where horses were excluded (Table 2).

Fig. 1. Global distribution of studies evaluating the impact of feral horses on populations of wild mammals.

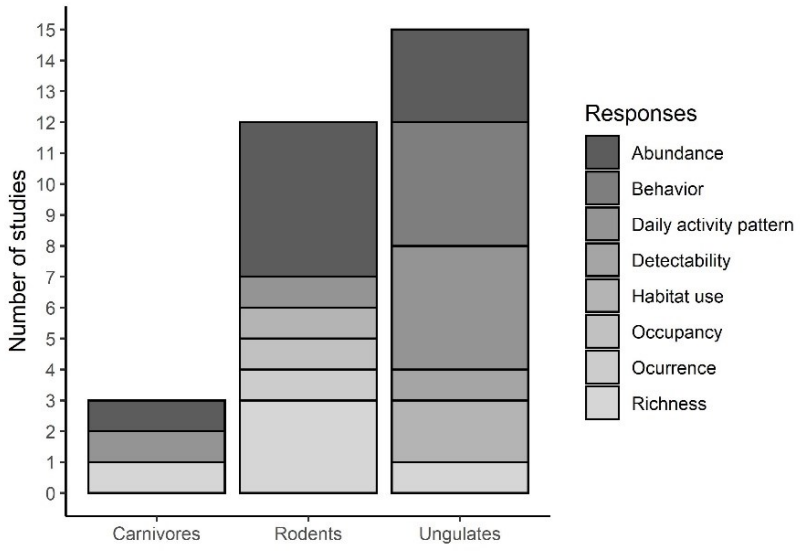

Fig. 2. Types of variable response used to evaluate the effect of horse grazing on wild mammals.

TABLE 2

Effect of horse presence on wild mammals, by taxonomic sub-group.

Taxonomic group	Effect of the presence of horses	Reference
Carnivores	Change in daily activity. Less number of visits and time of use of water source.	Hall et al. (2016).
Rodents	A decline in richness and abundance.	Beever and Brussard (2000).
	Changes in abundance.	Beever and Brussard (2004).

	A decrease in the abundance of burrows and individuals.	Ward–Fear et al. (2016).
	Less number of visits and time of use of the water sources.	Hall et al. (2016).
	A decrease in the probability of occupancy.	Cherubin et al. (2019).
	A decrease in the use of habitat.	Eldridge et al. (2019).
	A decrease in occurrence and abundance.	Schulz et al. (2019).
Ungulates	Subordinate during interactions with horses.	Berger (1985).
	Improved foraging performance and change in habitat use.	Coates and Schemnitz (1994).
	Changes in abundance.	Ostermann–Kelm at al. (2008).
	Subordinate during interactions with horses.	Perry et al. (2015).
	Less number of visits and time of use of water sources.	Hall et al. (2016).
	Increased time in surveillance behavior and decrease in foraging time. Subordinate during interactions with horses.	Gooch et al. (2017).
	A decrease in the frequency of use of water sources. Change in the daily activity pattern in water sources.	Hall et al. (2018).
	A decrease in density concerning the distance of the horses.	Arandhara et al. (2020).

DISCUSSION

During the initial search, the results showed a large number of studies, but after a detailed review, we found only a small number of articles analyzed the effects of horse presence on wild mammals. This pattern was also found by Eldridge et al. (2020), showing a lack of knowledge of the impact of horse presence on wild mammals. There seems to be a growing interest in understanding the effect of horse presence on wild mammals, but the increase in the number of publications is a general trend in many fields (Lisón et al., 2019).

Regarding the study sites, most of the research was conducted in the United States. In the early 1970s areas devoted to horse management in the United States covered 36,67 million hectares, and currently half of that still embraces horse populations in threatened ecosystems (Beever et al., 2018). Additionally, stakeholders such as ranchers, animal rights advocates, hunters, conservationists, and horse advocates are increasingly pushing decision-makers to adopt more rigorous, science-based methods and analysis to justify management actions (Beever, 2003). These factors have contributed to the high number of studies in the United State.

Our results indicated studies frequently focus on iconic species, agreeing with the results of Eldridge et al. (2020). Most studies analyzed the effects of horses on charismatic ungulates such as the pronghorn (*Antilocapra americana*) or the bighorn sheep (*Ovis canadensis*) (Coates & Schemnitz, 1994; Gooch et al., 2017; Hall et al., 2018; Ostermann-Kelm et al., 2008). Studies based on rodents also showed a trend to use charismatic species, such as the toothed rat (*Mastacomys fuscus*), a near-threatened rodent endemic to the mountainous regions of southeastern mainland Australia and Tasmania (Cherubin et al., 2019; Eldridge et al., 2019; Schulz et al., 2019). Moreover, few studies evaluated the effect of horses at community level (Beever & Brussard, 2004; Hall et al., 2016), requiring that future research tackle functional and structural changes caused by horse presence in ecosystems and biotic communities (Eldridge et al., 2020).

Most studies evaluated the effect of horses by correlating grazing factors with response variables such as abundance, activity, or behavior of wild mammals, often in combination with other

environmental covariates (e.g., soil compaction, vegetation cover, water availability). Some studies used existing ranch fences to exclude horses from bodies of water or pasture areas and thus evaluate the effect of horses on mammals (Beever & Brussard, 2000, 2004; Hall et al., 2016); however, the fact that only one study was experimental suggested the difficulty of logistics to carry out experiments and manipulate populations in the wild (Mishra et al., 2004). This could explain the low number of studies devoted to evaluating the effects of horses on wildlife.

The effects of horse presence on a global scale are consistent at regional and local scales (Davies & Boyd, 2019; Eldridge et al., 2020; Nimmo & Miller, 2007). Although the effects in mammals can be varied (Eldridge et al., 2020), this review shows a pattern of effect with regard the taxonomic group. Carnivores and ungulates showed direct effects due competition with horses, whereas rodents seem to respond primarily to changes that horses cause in the structural components of the habitat. A similar pattern was observed by Schieltz and Rubenstein (2016) who conducted a review of the impacts of livestock (excluding horses) on wildlife; the study suggested changes in structure and vegetation cover were significant for small mammals, and also the interference competition as result of horse presence as the most important trigger of negative responses on ungulates. For such large mammals changes in habitat structural components showed a positive effect, hence the open spaces made by large ungulates can shape the composition of plant communities and increase spatial heterogeneity (Bakker & Olff, 2003; Eldridge et al., 2020), though, in some cases the change caused by horse presence is often negative for habitat components and wildlife.

This review also identified patterns and current knowledge gaps about the effect of horse presence on wild mammals, therefore the summary carried out in this study can help to readdress further research by providing an organized summary of the spatial distribution information, methodological approaches, and variables used according to the different taxonomic groups. Finally, maintaining horse populations in protected areas could be contrary to conservation objectives. However, determining whether horse management within protected areas has positive or negative effects depends of *ad-hoc* management aims and the ecological and social implications, which may vary geographically, so it is desirable to support these management actions with empirical evidence. Owing to this, we recommend careful monitoring of horses and their potential effects on wildlife by using species proxies such as ungulates and rodents to determine whether horse presence in protected areas affects conservation objectives.

ACKNOWLEDGEMENTS

We thank Todd Fuller for commenting on this manuscript

ETHICAL, CONFLICT OF INTEREST AND FINANCIAL STATEMENTS

The authors declare that they have fully complied with all pertinent ethical and legal requirements, both during the study and in the production of the manuscript; that there are no conflicts of interest of any kind; that all financial sources are fully and clearly stated in the acknowledgments section; and that they fully agree with the final edited version of the article. A signed document has been filed in the journal archives.

The declaration of the contribution of each author to the manuscript is as follows:
B.H.M.C.: Literature review, analysis and writing the manuscript. E.C.J., V.M.G. and R.S.P. writing and review of the manuscript.

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APPENDIX

Appendix 1

Articles analyzing the effect of horses on wild mammals, and used for this review.

Arandhara, S., Sathishkumar, S., & Baskaran, N. (2020). Modelling the effect of covariates on the detectability and density of native blackbucks and invasive feral-horse using multiple Covariate distance sampling at point Calimere wildlife sanctuary, southern India. *Mammalian Biology, 100*(2), 173-186. https://doi.org/10.1007/s42991-020-00018-w.

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Appendix 2

TABLE 3

Classification of the 14 articles selected to analyze the effect of horses on wild mammals.

Year	Country	Group	Study type	Response	Effect type	Reference
1985	EE. UU	Ungulates	Cor	B	Direct	Berger (1985).
1994	EE. UU	Ungulates	Cor	B, HU	Diect	Coates & Schemnitz (1994).
2000	EE. UU	Rodents	NE	R	Indirect	Beever & Brussard (2000).
2004	EE. UU	Rodents	NE	A, R	Indirect	Beever & Brussard (2004).
2008	EE. UU	Ungulates	CE	A, DA	Direct	Ostermann-Kelm et al. (2008).
2015	EE. UU	Ungulates	Cor	B, DA	Direct	Perry et al. (2015).
2016	Australia	Rodents	Cor	A	Indirect	Ward-Fear et al. (2016).
2016	EE. UU	Carnivores, Ungulates, Rodents	NE	A, DA, R	Direct	Hall et al. (2016).
2017	EE. UU	Ungulates	Cor	B	Direct	Gooch et al. (2017).
2018	EE. UU	Ungulates	Cor	DA, HU	Direct	Hall et al. (2018).
2019	Australia	Rodents	Cor	O	Indirect	Cherubin et al. (2019).
2019	Australia	Rodents	Cor	HU	Indirect	Eldridge et al. (2019).
2019	Australia	Rodents	Cor	A, OC	Indirect	Schulz et al. (2019).
2020	India	Ungulates	Cor	A, D	Direct	Arandhara et al. (2020).

Study type: CE= Controlled experiment, Cor= Correlational, NE= Natural experiment.
Response: A= Abundance, B= Behavior, D= Detectability, DA= Daily activity, HU= Habitat use, O= Occupancy, OC= Occurrence, R=Richness.