COMMENT ON *'Independent biostatistical report on the Brumby population in the Kosciuszko National Park'*

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Contents

INTRODUCTION AND GENERAL REMARKS

What report is referred to?

The report I comment on *'Independent biostatistical report on the Brumby population in the Kosciuszko National Park'* dated 20 May 2023, is available at https://meetourhorsemeat.com/wp-content/uploads/2023/05/Independent-Biostatistical-report-into-the-counting-of-wild-horses-Claire-Galea.pdf. I refer to the report hereafter as Galea (2023).

Not a scientific process

It is important to recognise that neither Galea (2023), nor this commentary, have been subjected to the normal quality control processes that apply in science, i.e. they have not been published in a journal which deals with wildlife counting methods, which would have subjected them to serious editorial inspection, and the opinions of two or three anonymous peer-reviewers. Also there is the potential for subsequent criticism to be published later in the same journal.

However, any publicly available report such as Galea (2023), which is concerned with scientific matters such as the estimation of animal abundance, should rightly be open to fair criticism or comment on factual and scientific grounds. The justification for such evaluation is increased in this case because the report recommends a major change to the current management of Kosciuszko National Park. Also because the report has not only been placed on the internet, but also sent to the offices of most of the relevant politicians who are involved with management of feral horses in Kosciuszko National Park (KNP).

Not personal

Nothing in the following comments about the content of the report should be read as personal criticism of Mrs Claire Galea herself. I presume she is a fine professional in her own field, as evidenced by the impressive number of scientific papers which she has co-authored, and her acceptance by a university as a PhD student.

Similarity of wildlife controversies

Current controversies over management of feral horses in Australian conservation areas share some features with most other wildlife management controversies. It is particularly common for scientists' population estimates to be disputed. For example, many critics of wildlife management programs have little respect for ecological expertise, and believe there are no more animals present than they have observed themselves.

Importance of this response to Galea 2023

Galea (2023) has been claimed to be both 'independent' and to be based upon greater expertise than that of the professional ecologists and public servants responsible for the official counts of horses in KNP. However I show below that there are numerous deficiencies of science, logic and statistics in the report. On the basis of these deficiencies and the legal, ecological and ethical imperatives outlined below for feral horse population reduction, I challenge the only recommendation in the report, which is for *'Immediate moratorium on the killing of all wild horses in the Kosciuszko National Park and an independent investigation into all population trends and subsequent control needs to be urgently undertaken'*.

Independence

The report title says it is 'independent'. Presumably the reader is meant to infer that the report is unbiased because its author has no links to either side of the horse controversy in KNP. However perusal of the report uncovers instances where a more detached statistician would probably have made a more logical conclusion (see below) or avoided making an error of scholarship (identified below). This made me wary of the claim for independence.

The report displays no understanding of the legal, ecological and ethical contexts of the horse counts

The NSW *Kosciuszko Wild Horse Heritage Act* (2018) requires a horse management plan which recognises and protects wild horse heritage values in Kosciuszko National Park and enables active management of the wild horse population to reduce its impact on the park's fragile environment. Consequently, the Kosciuszko National Park Wild Horse Heritage Management Plan (the Horse Plan) was adopted by the Minister for Energy and Environment on 24 November 2021 following a massive exercise in democracy, including extensive consultation with expert committees, thousands of public submissions and the approval of several key Cabinet Ministers in the NSW Parliament, including the Deputy Premier, John Barilaro who was responsible for introducing the bill that required the plan to be prepared. The Horse Plan, a binding legal instrument, requires the current horse population (estimated in 2022 to be ~19,000) to be reduced to 3,000 by 30 June 2027.

A further requirement for horse population management has been established by the listing of *'habitat degradation and loss by feral horses'* as a Key Threatening Process in Schedule 4 of the NSW *Biodiversity Conservation Act* (2016). The NSW government is thereby required to ameliorate the biodiversity threat where possible.

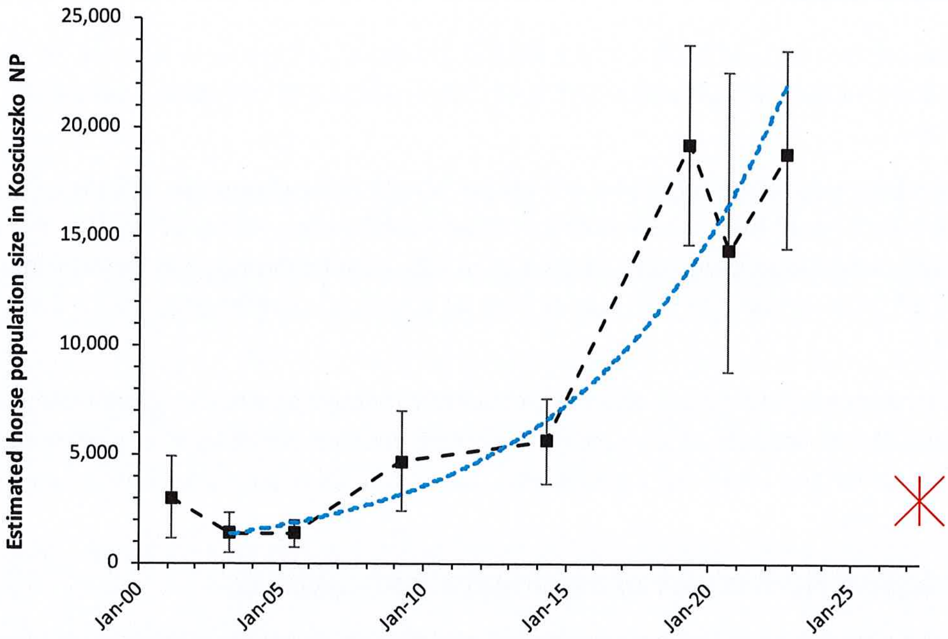
Scientists have estimated the size of the horse population in KNP nine times. The first was in the late 1980s by Dyring (1990). Eight estimates since 2001 all used Helicopter Line Transect Distance Sampling (HLTDS), a method explained below. For years, the exponential increase of the horse population has been plainly evident to anyone who has been interested in the counts (Figure 1 and Appendix table).

It is the nature of exponential population growth to seem slow for a long time while the population is relatively small, then to seem to increase rapidly when the population is larger. Thus the risk to native Australian species of animals and plants has become more acute in the last few years, now that the horse population is large and increasing rapidly.

As a result, although the first horses entered the area more than 100 years ago, in 2023 many plants and animals in the park will be encountering horses for the first time. Others will be experiencing high levels of horse impact for the first time.

Scientists have been pointing to the increasing threat to biodiversity associated with the increasing horse abundance and distribution for 70 years, since 1953. But now it has become worse than a threat, with actual loss of populations having occurred due to horse activity; e.g. populations of tooarrana *(Mastacomys fuscus)* have been lost (Driscoll *et al.* 2019; Eldridge *et al.* 2019; Schulz *et al.* 2019) most likely through reduction of ground layer vegetation which is essential for this native rodent to persist (Cherubin *et al.* 2019). Thus, even if there was not the legal imperative requiring management of the horse population, there are clear ecological and ethical imperatives to act.

Figure 1: Eight estimates of the horse population in KNP (squares) were accompanied by wide 95% confidence intervals (error bars). But overall there has been a consistent trend of 15% annual increase (dashed blue curve) since the 2003 bushfire, except around the time of the 2020 bushfire. The red star marks the commencement of the requirement for there to be only 3,000 horses from 30/6/27. See the Appendix for details.



In this legal, ecological and ethical context, there is no option to recommend that the horse population should not be reduced. Yet that is the only recommendation of this report (Galea 2023, p. 4). On that basis, the report can be regarded as being somewhat adrift from the current legal, ethical and ecological circumstances. In addition there are numerous flaws in the case it presents for doubting the horse counts, as detailed below.

The report does not suggest a better survey method, or provide any way forward

The Horse Plan indicates that feral horses can be found in 53% of the 6,900 sq km KNP, i.e. in an area of 3657 sq km. This area probably includes all places where rangers have seen groups of horses, but counting is limited to a smaller area where horses are more likely to be encountered, i.e. 2,745 sq km. No experienced ecologist would imagine that a population of wild horses spread over even this 2,745 sq km part of KNP could be reduced accurately to 3,000, from more than 10,000 individuals, without further counting. And the estimated population size in 2022 was not 10,000 but was almost twice as large, i.e. 19,000 approximately (Cairns 2022).

As the horse population is reduced closer to the target population size, counts of good precision and accuracy will be needed more frequently than ever before, to guide the culling program so that it achieves a result of acceptable precision and accuracy. The legal, ecological and ethical imperatives referred to above make horse control, and therefore horse counting, essential between now and June 2027. The most suitable counting method available for the terrain and population size at KNP is Helicopter Line Transect Distance Sampling (HLTDS) (Walter and Hone 2003), which is the method used for all eight surveys carried out in the last 22 years.

Galea (2023) identifies many causes of claimed inaccuracies. However, the report does not state whether the claimed problems would make the counts too low, or too high. The important question of whether the claimed inaccuracy is positive or negative appears not even to have been thought of. The author has simply assumed that errors would result in overestimation of horse abundance.

No counting method is perfect. Internationally, distance sampling has more often underestimated than overestimated, and in particular, distance sampling has been shown to be underestimating the count of horses in KNP (Laake *et al.* 2008). If all the methodological deficiencies claimed in Galea (2023) were real, there may be far more horses than suspected and an even greater problem than experts currently appreciate.

Another conceptual omission from the thinking behind the report is the lack of any way forward; which is an extremely important gap, considering the legal, ethical and ecological imperatives mentioned above.

No wildlife population estimation method is perfect but unless some alternative or improvement can be identified, it is fruitless to focus much attention on any deficiencies. Galea (2023) does not outline how an alternative population estimation method to HLTDS could be deployed in the terrain and vegetation of KNP. (In some parts of KNP even helicopter counting is challenging, due to the terrain and vegetation.)

In fact the report does not refer to any alternative scientific method of measuring population size. It simply states (p. 12) that because of (claimed) deficiencies, distance sampling is '*not appropriate methodology for estimating wild horse populations*'. It does not name any other survey method which might be superior.

The report suffers from a lack of experience with ecology

The author of the report is an experienced medical statistician whose name is included in the author-list of a large number (~50) of papers published in peer-reviewed medical journals. Possibly she provided the statistical services needed for data analysis in those projects. Galea is also listed on the Linked-In website (https://www.linkedin.com) as a PhD candidate in the Faculty of Medicine at Macquarie University, Sydney. An on-line article from the university says Galea is '*leading the world's first global evaluation of Dolly Parton's Imagination Library including a research focus on children in the NSW town of Tamworth*'.

I found no evidence of ecological training or experience in Galea's background and there is nothing like this report (Galea 2023) published in any ecology journal. Measuring the abundance of wildlife is a notoriously challenging area of ecology which requires not only skill with the particular statistical challenges of ecology (e.g. see 'B2 Transformation of the data – p. 12') but also a good deal of field experience. The report reads as if it rests on limited field experience in ecology.

In estimating the numbers of horses in national parks like Kosciuszko, the challenges include the impossibility of uniquely identifying all the individual horses in large populations* and the impossibility of seeing all the horses on any one occasion. In the medical studies co-authored by Galea, each person involved would have had unique identifiers (name, date of birth etc). And there is no evidence that Galea's research has involved patients who could not be seen by the researchers. Thus Galea's extensive experience in medical statistics appears unlikely to include experience in two of the main challenges of counting wild animals.

* Individual identification of horses <u>can</u> be used to estimate population size by Mark-Resight analysis, if the population is small enough. Dawson and Miller (2007) observed 50 horses in a 180 sq km area of the Bogong High Plains when they searched it by helicopter one day. The next day they searched it again and recorded 78 individuals. Some of these were seen more than once on the same day and the total number of individual horses seen on either day was 72. From this, the population was estimated to be 89 to 95 horses (so 23% to 32% of horses were never seen on either day). The statistical analysis used the well known Mark-Recapture method. The authors speculated that the method may have practical application for aerial surveys of small populations, subject to methodological improvements such as a change to video rather than still imagery to recognise individual animals (Dawson and Miller 2007). The method of recognising individual horses was not considered suitable for estimating the number of horses to be counted in KNP, which is hundreds of times more. Nor does the counting budget allow time for horse photography and the careful observation required with this method.

Too many simple mistakes

There is a distinct impression that the report (Galea 2023) was written in haste because it has so many simple errors. One example is the mistaken claim that the Kosciuszko HLTDS surveys do not count foals separately (Galea 2023, p17). Yet the foal counts are obvious in the 2020 and 2022 reports. In Cairns (2022), the foal counts are mentioned in the Summary, in the Methods, and in the Results and Discussion. And they occupy more than two entire pages. (see more details in my response to criticism C3). Similar mistakes are mentioned in my comments on criticisms 'B1 – Statistical modelling', 'B2 Transformation of the data', 'B3 - Use of covariates' and 'B4 - Assumptions'. Also there is repetition of the same criticisms under different headings.

The prevalence of such easily identified errors (no statistical knowledge needed) might lead a reader to lose confidence in the main claims of the report.

It is the latest survey (Cairns 2022) which is the most important so it is odd that the report gives no reason for its focus on the 2014 and 2019 surveys with only occasional mention of the latest (2022) survey, and no mentioned at all of the 2020 survey which was completed between those surveys that are mentioned. The omission of the 2020 count report from Galea's criticism was probably just an oversight, and not because Galea approved of the 2020 count.

About the horse counts to date

Over the past 22 years, the feral horses in Kosciuszko have been counted eight times by a number of different people from independent universities and the NPWS. Until recently, most of the counts were funded by the Australian Alps Liaison Committee (AALC), and most provided a single combined estimate of the horse population of the alpine national parks in Victoria and NSW.

In spite of limitations, collectively the set of eight horse counts has provided a consistent and plausible result (Figure 1). The counts are remarkably consistent in showing an average annual increase of 15% except when the horse population was reduced by the bushfires of 2003 and 2020 (Figure 1).

As previously mentioned HLTDS was the method used for all surveys. In the name 'Helicopter Line Transect Distance Sampling', the words 'line transect' refer to the straight lines from which the horses are observed. These transects are parallel east-west lines (in one or two cases over the 20 years a different direction was used in small steep areas) and within a survey block the lines are equidistant (*e.g.* Cairns 2022) so this design is referred to as a 'systematic' layout. Each set of transects has a randomly chosen start point, hence the design is sometimes referred to as 'systematic random' (*e.g.* Cairns 2022). 'Distance Sampling' refers to the analytic method used for statistical analysis of the data, typically using the free program '*Distance*' or an equivalent package in statistical program R. (There are other ecological methods based on transect lines which are not distance sampling and there are other examples of distance sampling which are not from lines or which are not done from helicopters).

In brief, Distance Sampling exploits the fact that fewer animals are detected at greater distance from an observer, in order to enable an estimate of how many animals are not seen, in addition to those which are detected and recorded. The Distance Sampling method (Thomas *et al.* 2010 and https://distancesampling.org/whatisds.html#online-bibliography) is one of the most widely used methods in the world for estimating abundance of wildlife populations. Its mathematical and statistical foundation is comprehensively explained in two books, particularly Buckland *et al.* (2001), and a second book covering more advanced applications (Buckland *et al.* 2004). The results have been evaluated against known populations on numerous occasions and found to be accurate (*e.g.* Hone 1988; Hounsome *et al.* 2005; Glass *et al.* 2015). Thousands of published, peer-reviewed scientific papers exemplify its use. More than 1,400 of them can be found in the bibliography at https://distancesampling.org/dbib.html. There is a wide range of species whose populations have been counted using Distance Sampling, including insects, crabs, fish, reptiles, antelopes, deer, kangaroos, feral pigs, fruit bats, primates, polar bears, whales, dolphins and mice, as well as inanimate objects such as birds' nests, mammal burrows and carcasses (Buckland *et al.* 2001 p11). There is no reason to doubt the Distance Sampling method itself.

In the Australian Alps, HLTDS has been compared to two other counting methods to estimate abundance of horse populations. The study authors recommended HLTDS for future use (Walter and Hone 2003). Since then, the design, analysis and reporting of recent surveys by Cairns (2019, 2020, 2022), and the results obtained, have been reviewed and found acceptable on several occasions by different groups of truly independent scientists who are themselves experienced with statistical analysis of wildlife counts. Overall, there has been a considerable body of scientists who approve of the use of HLTDS, and how it is being applied in KNP to estimate horse abundance.

Aside from the three methods compared by Walter and Hone (2003), only one other method of counting feral horses in the high country has been peer reviewed and published (Dawson and Miller 2007). It relies on recognition of individual horses in small sub-populations, as explained above under the heading 'The report suffers from a lack of experience with ecology'. But it is not the earlier surveys which matter. The most recent survey (Cairns 2022) is the most important for horse management.

The length of transect traversed in the latest survey (survey effort) was 1,496 km. To traverse this distance in a much slower platform than a helicopter (for example on horseback) would contravene statistical requirements (see below) as well as being impractical. To survey a shorter length of transects by helicopter would result in a higher coefficient of variation (i.e. greater uncertainty around the population estimate; see below). There seems almost no chance that a ground based survey method could be found which would enable the horse populations in KNP to be estimated reliably across their full extent.

Accuracy and precision are less important now than later

The upward trend in the horse population is obvious (Figure 1) and corresponds with the experience of long-term observers who have seen at first-hand the horse distribution expanding and the abundance increasing. The expanding distribution of horses has also been reported by several observers including Dawson (2009).

What is apparent from Figure 1 is that previous and current population control measures have not reduced the size of the horse population, nor its rate of increase. While the horse population is growing exponentially, each year the number of horses moves further from the target of 3,000 and the distance it moves away from the target is greater every year.

Therefore at the present time, there is a limit to the importance of accuracy and precision of the count. Count accuracy and precision will become more important after the commencement of a horse control method which has the capability to reverse the current trend and cause the population to move toward the target of 3,000 individuals. Rather than wasting funds and human effort on greater precision and accuracy when the horse population is in the range of 10,000–30,000 individuals, it would be better to focus on the attainment of a program which can actually reduce the horse population as required, and save the counting precision for when it will be needed.

Therefore a detailed discussion of claimed statistical imperfections in the horse count (Galea 2023) is of limited use or importance at this time.

COMMENT ON PARTICULAR CRITICISMS IN GALEA 2023 –

1 Cluster size – page 6

In spite of the title, this criticism is actually about the number of clusters. My response is in three parts.

Ecologically naive statistical approach which is aimed at the wrong survey

The main criticism under this heading is that in some sub-populations of horses counted in the 2014 and 2019 surveys, the number of clusters was below the minimum number recommended for Distance Sampling, i.e. 60. It is the latest survey, conducted in 2022, that should be our main focus but for an unknown reason, this particular criticism is applied only to the 2014 and 2019 counts.

The aim of the surveys was to estimate the number of horses in the Australian Alps (Cairns2014, 2019) or in KNP (Cairns 2022). Therefore both surveys necessarily and rightly included some areas of high horse abundance and some areas of low horse abundance. For all three surveys the total number of clusters was well beyond the minimum of 60 required, i.e. 301, 458 and 419, respectively. The number of clusters was fewer than 60 only in some sub-component areas. Surveys across the range of horses within KNP (or of any species anywhere) inevitably must (and should) include areas where the population is advancing into new areas, or for other reasons is at low density. In these sub-components of the surveyed area it is inevitable that fewer clusters will be recorded than elsewhere. In the 2022 survey fewer than 60 clusters were observed only in the Snowy Plain sub-population, i.e. 47 clusters.

More funds would have enabled more counting over the same ground until at least 60 clusters were seen at Snowy Plain, in order to obtain a better estimate of the number of horses in that site and keep at bay any criticism such as that in this report. (The extra survey effort in that small area would not bias the result, contrary to Galea's Criticism 4, as explained under that heading.) But it would be wrong to apply extra effort to Snowy Plain for a different reason, i.e. because Snowy Plain contained only 4% of the total horse population, so a small improvement in the estimate there would have made negligible difference to the total count. If extra counting could have been done, the effort could have been used more efficiently in the open plains of northern KNP which contained 68% of the estimated population.

The number of clusters counted in the Bago Maragle block in 2014 and 2019 is also criticised on p. 7. The Bago-Maragle block (on the western edge of KNP near Cabramurra) contained 11% of the horses seen in 2014 and only 4% of the horses seen in the 2019 survey. The same comments apply to this criticism.

The *Distance* computer program allows for stratification across different surveys, and after the 2019 survey, Cairns (2019) combined the data for this block from both surveys to obtain a better population estimate. Galea (2023) raises theoretical concerns with the practice of combining surveys, and concludes 'no reliable population estimates can be determined'. Galea (2023) does not indicate what alternative action Cairns (2019) could or should have taken, but the obvious alternative would be a foolish one, to reduce the survey effort where horses were abundant in order to spend more survey effort counting such places as Bago–Maragle where they were uncommon, until more than 60 clusters were seen in each and every sub-population. Instead, by combining results from both surveys, Cairns (2019) has prudently responded to the reality that some survey blocks have few animals.

The report goes on to compound this misunderstanding by complaining that the number of clusters seen in the individual 'medium terrain' stratum within the north Kosciuszko block are too few. The point is that the numbers of clusters seen in the whole block are sufficient, i.e. 84 + 20 =104 in 2014 and 226 + 43 = 269 in 2019. Note that the numbers in the table on p. 6 of Galea (2023) are correct, but mistakes were made when they were repeated in the text on p. 7.

Criticism of kangaroo counting exemplifies ecological naivety

On page 6 of Galea (2023) there are two tables labelled 'Table 3'. The second one presents data from a kangaroo count in New England. The table shows the numbers of Eastern Grey Kangaroos, Wallaroos, Red Necked Wallabies and Swamp Wallabies counted by HLTDS. The district count was subdivided into six sub-component areas. Several of the counts in sub-components recorded fewer than 60 clusters, but never for the main species of interest, the Eastern Grey Kangaroo, only for Wallaroos or the two Wallabies, which are evidently much less common in these areas than Eastern Grey Kangaroos. In these circumstances it is absurd to complain that the uncommon species did not record 60 clusters. I will explain using an example - in semi-arid western NSW where Red Kangaroos and Western Grey Kangaroos dominate, the occasional Eastern Grey Kangaroo is found in some years, but they are less than 0.1% as numerous as the primary species. It would be absurd, and perhaps impossible, to try to record 60 clusters of Eastern Grey Kangaroos in such places. All species are not common in all habitats! However there is an interest in any change over time in the relative abundance of them all, and in their conservation, so it makes sense to record them.

Misunderstood meaning of 'cluster'

The report has misunderstood the meaning of 'cluster' in Distance Sampling. It states that '*a cluster is considered to be more than one animal*'. In fact, the recording and analysis of data in Distance Sampling is based on the reality that animals occur in all sizes of groups or clusters from 1 animal upward (Buckland *et al.* 2001). And, this is a central feature of the method. The importance of clusters arises from the Distance Sampling developers' insistence on rigorous statistical standards, as explained in the next paragraph. If Galea's definition of clusters were adopted, all the animals seen as singletons would be omitted from the count.

To understand clusters in Distance Sampling, we begin with the statisticians' awareness that when an observer has seen one of the animals in a group, there is an increased likelihood that other animals in the group will also be seen. So if animals were recorded separately, as if they had been detected individually, the variance of the population estimate would be underestimated. To achieve impeccable statistical rigour, the observer in Distance Sampling is required to record details of animal clusters (i.e. groups) and the data analysis is done in two parts. The density of animal groups or clusters is estimated (i.e. average number of clusters per unit area) and its variance. Separately, the average size of clusters is estimated, and its variance. Then the two are combined. (In reality however, the analysis is more complex, for example the estimate of group size is usually done as a regression of distance from the observer because observers tend to perceive larger groups at greater distance -Buckland *et al.* 2001).

2 Cluster observation – page 7

The report says *'given insufficient clusters of wild horses .... were seen .... No reliable population estimate can be determined'*.

First, it is not true that insufficient clusters were seen, as explained above. Second, Galea's criticism that mean cluster size is prone to be affected by outliers, reveals a misunderstanding of the mechanics of cluster size analysis in the *Distance* computer program. The estimation of mean cluster size is based on the regression of size over distance (not a simple mean) and has been considered valid by numerous statisticians of international repute. On this point Galea (2023) is incorrect, statistically speaking.

3 Lack of precision – page 8

The criticism here on p. 8 is repeated on p. 15 where it is headed 'B8 Width of the confidence intervals'. One small difference is that under this heading the report focusses on Cairns (2019) but under heading B8 it is Cairns (2022) which is criticised.

To avoid repetition, and because the latest count is the one which matters most, I have responded to this point under B8.

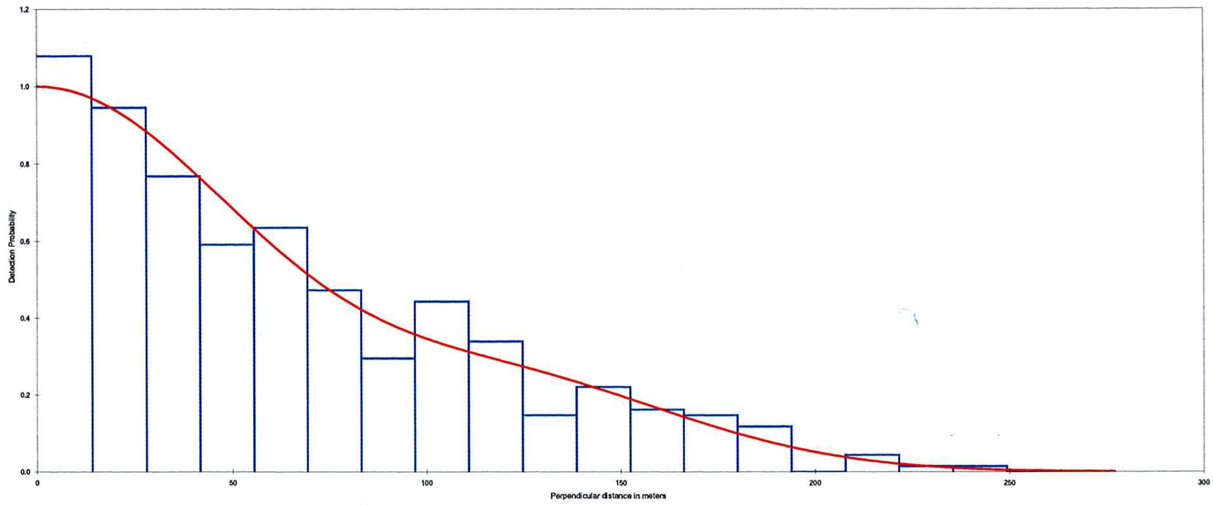
4 Bias sample location – page 11

The report is concerned that counting effort should be applied evenly across the distribution of horses to avoid bias. This comment is plain wrong statistically. It is perfectly acceptable, and in some cases desirable, to apply different levels of survey effort in different parts of an area being surveyed, in order to improve accuracy or precision of the result of the survey (Buckland *et al.* 2001). In Distance Sampling, additional effort can be applied within a stratum, potentially to improve precision and the estimation of the shape of the detection function (explained below). This would improve the accuracy of the estimate of density (horses/sq km) for that stratum. The estimates of the number of horses in the individual strata are subsequently combined to obtain the total population in the counted areas.

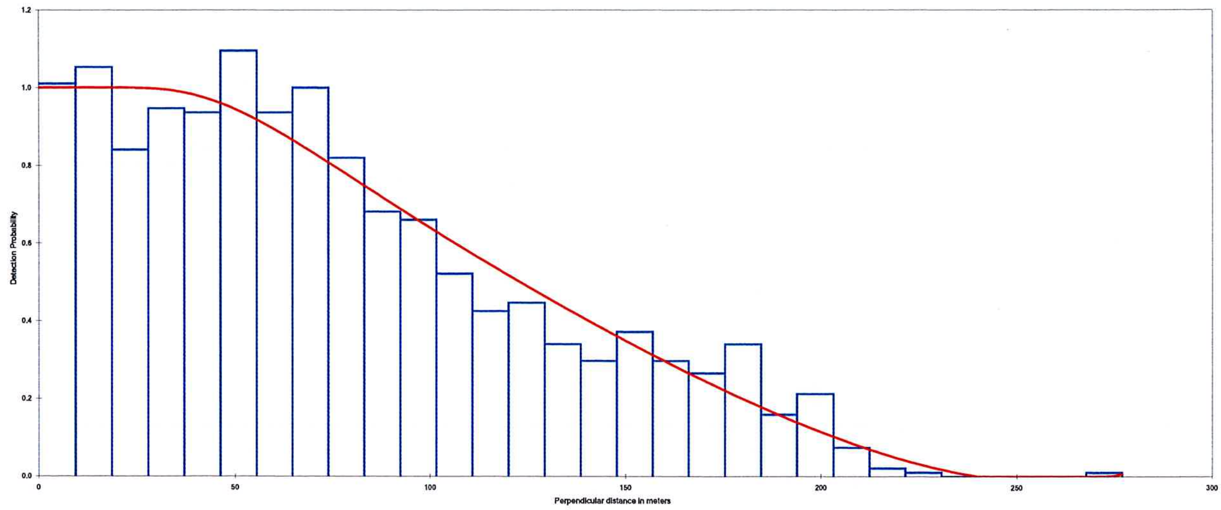
The detection function is the mathematical equation that best describes the proportion of animals present that were actually seen and recorded, as a function of distance from the transect, as illustrated below for two kangaroo surveys. It is a model representing the probability of detecting an object in relation to the covariate of the perpendicular distance that the object might be from the transect centreline, and any other relevant covariates that are measured and recorded. In relation to this is the expectation that objects on the transect centreline (x = 0) will be detected with certainty (g(0) = 1).

Figure 2: Different detection functions in Distance Sampling: bars indicate the proportion of clusters recorded at particular distances from the transects; and red lines are the equations that best describe the shapes of these relationships, (a) a half normal equation with cosine adjustment and (b) a hazard rate equation. Because the transect lines are on a random systematic pattern, in a properly conducted survey it can be safely assumed that on average there will be, in reality, an equal number of clusters at all distances from the transect line. The red lines show the proportion that were seen by the observers.

(a)



(b)



<u>5 Use of line transects with respect to speed of wild horses – p. 12</u>

The report asserts that HLTDS (referred to as '*use of line transects*') is '*not appropriate methodology for estimating wild horse populations*'. Strong claims such as this require strong evidence but the assertion is not even lightly supported with evidence. Also, one might ask what survey platform should be used to count horses if helicopters are too slow to do the job? A large body of highly qualified statisticians with impeccable reputations disagrees with Galea's (2023) assertion. Galea's claim is based on three things:

(i) Advice given by Buckland *et al.* (2001, p. 31) (which was repeated in notes for university students by Owusu 2019, which is the reference cited by Galea) that in order for mobile animals flushed by the survey platform to be recorded at their original location, the animals should travel at no more than half the speed of the survey platform.
(ii) The helicopter speed when counting horses is 93 km/h (Cairns 2022).
(iii) Reference to a web page about racehorses in North America to state that horses can run at 64 km/h.

During counting operations, the feral horses in Kosciuszko do not behave like trained thoroughbreds being ridden hard along the mown track at a racecourse, possibly urged along with whips and spurs. When flushed, the Kosciuszko horses do not move half as fast as the aircraft travelling at 93 kph, at least not for any appreciable distance. In practice it is almost always possible to record their original location, which is all that is required by the Distance Sampling method. Even wild horses which had recently had a bad experience of helicopters, responded to a counting helicopter by moving only 1 km on average from their starting point (Linklater and Cameron 2002).

In any case, it is likely that the theoretically based advice given by Buckland *et al.* (2001) is of a precautionary nature and can be carefully disregarded without biasing the population estimate. My former staff and I compared three counting methods to estimate kangaroo population size in five nature reserves, including Walked Line Transect Distance Sampling (WLTDS) from 220 km of transect. Other methods were Total Counts and Faecal Pellet Counting. For the WLTDS, the observers were required to travel at only 1 km/h. Flushed kangaroos usually travelled much faster than this, yet the population estimates by the three methods were the same. That is, the population estimates were neither significantly different statistically ($p< 0.05$), nor was there any consistency in which method produced the highest or lowest estimate in a reserve (Snape and Fletcher, unpublished data). So the advice about speed of the survey platform in relation to the speed of the animals is not an absolute requirement.

Horses in different countries are comparable to a reasonable extent so Galea's reference to a North American source for the maximum speed of a racehorse is perfectly legitimate but it is inconsistent with her complaint on p. 16 that the examples of high population growth of feral horse populations (Cairns 2019) were observed overseas, as if that somehow makes them less valid.

B1 Statistical modelling ... requires ... three time points – p. 12

The report (Galea 2023) says the 2019 count report '*applied complex statistical modelling techniques*' to data '*comprising only two points*'. Without a more specific reference, it is hard to be sure what this refers to. Most of the modelling in the report is based on the clusters, of which there were 458 in total. So I assume this comment refers to the bootstrap calculation of variance for the population growth rate between the 2014 and 2019 population estimates on p. 40. That is not statistical modelling in the normal sense that most readers would assume. And it is done to calculate the variance of the population growth rate, not the population growth rate itself.

It is perfectly legitimate, and commonplace, to calculate a population growth rate (PGR) between two counts. For example if the population of Melbourne was 2.5 million people in 2010 and 3 million a year later, we might say it had grown 20% that year. And use of the bootstrap method to calculate an estimate of variance around the PGR is also legitimate, and is far better than having no indication of variance, which is the alternative. If indeed this criticism refers to p. 40, it is a surprising one because the method is widely adopted by statisticians.

B2 Transformation of the data – p. 12

Galea (2023) states:

> '*When applying statistical modelling techniques there are various assumptions that the data need to meet in order to apply the techniques. The main one used is for the data to be what is called "normal", that is the raw data follows a normal distribution. When the data does not adhere to this then it is common practice to apply a transformation to the data depending on the shape of the original data. Cairns (2019) states that the* "estimates of cluster density and population density were slightly positively skewed, indicating that the data were not normally distributed"'.

Galea (2023) then goes on to speculate that Cairns (2019, 2022) may have applied a log transformation to the data in an incorrect way (by not accounting for zero values) and concludes:

> '***CONCERN:*** *If log-transformations are being applied to the raw counts, then all 0 counts will need to be increased and could significantly overestimate the population. Appropriate transformations should be applied that take into consideration 0 counts*'.

This section displays limited experience working with ecological data. First, the report makes the mistake of thinking of data that are not normally distributed as a problem to be fixed, but this is the wrong outlook. Ecological data are almost never normally distributed and therefore require the use of appropriate statistical methods and distributions in their analysis.

Log transformations, or any other transformations, were not needed in this case (not that they are problematic anyway, if applied correctly). Cairns (2019, pp. 36-37) states "*Bootstrap coefficients of variation and confidence intervals were calculated for all estimates, with the bootstrap confidence intervals being given in preference to standard normal-theory confidence intervals (Tables 7 and 8). This approach is becoming more common and is recommended because it relaxes the constraint of assuming that data are normally distributed and [that] confidence intervals are therefore symmetrical (Crawley 2005). The confidence intervals for both the estimates of cluster density and population density were slightly positively skewed, indicating that the data were not normally distributed.*"

So, in short, no transformation was used.

Galea (2023) is incorrect that data need to be normally distributed. It depends what procedure is being used. The comment about log-transformation is based on a total lack of evidence and in spite of the description by the author which clarify that no transformations were involved (Cairns 2019, pp 36-37). This is most likely another example of a criticism written in too much haste but the result has the unfortunate appearance of an attempt to make a target where there is none, or in other words to 'create a straw man' for the purpose of having something easy to criticise.

B3 Use of covariates – p. 13

Galea (2023) says that the count reports (i.e. Cairns 2019, 2022) do not make clear which covariates were used in the detection function modelling and that the reports are 'confusing' in this regard. Galea (2023) concludes '*Determining what covariates were included* *and what impact they had on the accuracy of the models cannot be determined from the reports given the conflicting information provided and therefore the generalisability of the results across the entire four blocks should be interpreted with caution'.*

In fact, the opposite is true. Cairns (2019, 2022) is quite clear about what was done and why. It appears likely that Galea simply overlooked the important words on this topic in both reports, i.e. 'CDS' and 'MCDS', which stand for Conventional Distance Sampling and Multiple Covariate Distance Sampling. As the name suggests, covariates are used with MCDS. Covariates cannot be used with CDS.

Unfortunately, Galea's quotations from Cairns (2019, 2022) omitted the crucial information which answers her criticism. I provide the full text from Cairns (2019) in the two following paragraphs, with underlined text indicating the words that were quoted by Galea (2023) as evidence of *'confusion'*.

On page 19: '*DISTANCE 7.3 has three different analysis engines that can be used to model the detection function (Thomas et al. 2010). Two of these, the conventional distance sampling (CDS) analysis engine and the multiple-covariate distance sampling (MCDS) analysis engine were used here. In analysing survey results using the CDS analysis engine, there is no capacity to include any covariates other than the perpendicular distance of a cluster of horses from the transect centreline in the modelling process. .... If the MCDS analysis engine is used, additional covariates can be included in the analysis.*

On page 21: '*The MCDS analysis engine allows for the inclusion in the detection function model of covariates other than the perpendicular distance from the transect centreline (Thomas et al. 2010).* ...... The covariates used in these analyses were related to individual detections of clusters of horses and were identified as observer, cloud cover score and habitat cover at point-of-detection. All these covariates were categorical. There were three observers (DS, MS and SS), three grades of cloud cover (1 = clear to light, 2 = medium, 3 = overcast to dull) and two categories of habitat cover at point-of-detection (1 = open, 2 = timbered), indicating that horses were either sighted in the open or in timbered habitat. The three covariates were included in the analysis either singly or in pairs.'

In regard to the quoted text Galea (2023) says:
'It is unclear throughout the report from Cairns (2019) as to what covariates were included and when. On page 19 it states that *"there is no capacity to include any covariates other than the perpendicular distance of a cluster of horses from the transect centreline in the modelling process"* yet on page 21 it states that *"The covariates used in these analyses were related to individual detections of clusters of horses and were identified as observer, cloud cover score and habitat cover at ....".*

The evidence shows that it was Galea, not Cairns, who was confused. And it was Galea who was responsible for creating confusion by making an incorrect criticism and misquoting (by omission).

The report (Galea 2023) goes on to apply the same level of scholarship to the corresponding sections of Cairns (2022).

Then there is a third mistake under this heading. Referring to a kangaroo counting report (Cairns 2016) Galea (2023) conflates the listing of putative co-variates for statistical evaluation (such as would be found in the Methods section of a scientific report), with the reporting of which of these putative co-variates had come through the statistical evaluation to prove worthy of retention in the model (typically found in the Results section). This is a surprising mistake for an experienced statistician to make. It is yet another instance in Galea (2023) where ordinary normal text by Cairns (2019, 2022) has been misunderstood or misquoted.

In summary, the criticism under this heading is wrong. The horse counting reports of Cairns (2019, 2022) are not confusing in regard to co-variates.

B 4 Assumptions – p. 14

The report quotes Cairns (2019) who, in full, stated:

'There were parts of each block that were not surveyed either because of the steepness of the terrain or because the land was under private ownership and were therefore not included in the calculations of population abundance (see Section 2.1). ......

Given along with the population abundances in Tables 9 and 10 are a second set of population densities. These are densities derived in relation to the total areas of the survey blocks. Implicit in their estimation are the assumptions that the horse population in a block would be aggregated in its distribution and that the density of horses in the very steep country within the survey blocks would be at trace levels; i.e. *near to zero. This assumption could be open to challenge, but could only be refuted with comparable survey results.'*

In the quoted paragraphs, Cairns is explaining his assumption that there were no horses in the areas he did not count. If that assumption is wrong, then the population size will have been UNDERestimated. Yet Galea comments that *'without comparable survey results there is no way of knowing if this assumption had a significant impact on the ... population estimates'*. (Is this an 'own goal' by Galea?) Again, no practical alternative is suggested. To apply counting effort where horses are so sparse that they probably can't be detected from the helicopter, would not be reasonable.

B 5 Grouping of Zones for modelling – p. 14

Galea (2023) states that *'In both the [Cairns] 2019 and 2022 reports the populations across the blocks are merged with a global detection function model applied and a single estimate determined. However, it is clearly evident from the report that the blocks provide significant differences in the wild horse counts along with the sizes and expected detection being different.*
.....
CONCERN: *Independent modelling of the four blocks should be undertaken and no overall population estimate reported.'*

This too is wrong. Cairns (2022, p. 2) states *'The survey of the wild horse population in KNP was conducted in four survey blocks that were identified by NSW NPWS as being in areas known to support wild horses'*. A different level of precision was specified for each block as presented in Table 1 on p. 2 of Cairns (2022), ranging from 20% to 40%. (Precision refers to the uncertainty or variance of each estimate, or in other words, the relative length of the error bars shown with each estimate).

Because of the requirements for different levels of precision the blocks could not be combined into a single analysis, nor were they. Tables 4, 5, 6, and 7 (Cairns 2023) present results separately for each block.

B6 No increase in the population over 2 surveys – p. 15

The point is made by Cairns (2022) that the higher population estimate in 2022 is not significantly different statistically (at the conventional 0.05 level) from the count in 2020. It may seem paradoxical to those without ecological experience, but that does not mean the population is not increasing.

The reason is that because all estimates of population size have a confidence interval, estimates that are close enough in time can not differ significantly (Figure 1). An example may communicate this better, so imagine a population of animals that is increasing constantly. If the population size is estimated often enough, e.g. every day or every week or every month, consecutive estimates would not differ from each other by very much even if the confidence intervals around the estimates of population size were unrealistically small (say 5%). Yet we know for certain that this hypothetical population is increasing because we made it that way. The answer is not to spread out the time between counts so that the differences between consecutive counts will be significant. The opposite is true, the more often we count the population, the better we will know it.

The answer is that testing whether consecutive counts are significantly different is a poor way to determine whether a population is increasing, stable or decreasing. There are better ways described in many ecology textbooks (but I do not need to go into them here). Suffice it to say that the horse population is probably still increasing, but even if it were stable, Galea's assertion that this would mean culling should stop is illogical.

The need to reduce the horse population is determined by the impact of the number of horses and by whether the number is higher or lower than the statutory requirement to achieve a population of 3,000 horses. The requirement for culling is unaffected by whether the number is increasing, decreasing or stable. To explain in an easier way, using an example, Galeas' assertion is like claiming that no parachute is needed when jumping from aeroplanes flying level, only for aeroplanes that are climbing.

B7 Implausible population estimates – p. 15

The 2019 survey actually saw and counted 1,374 horses, from which the population was estimated to be 15,687, which is 11.6 times as many. Galea evidently thinks this ratio is too high. But it is often unavoidable in ecology, e.g. the leading edge application of thermal drone technology (Brack *et al.* 2023) which estimated the population of swamp deer in Sesc Pantanal Reserve, recorded 66 deer from which they estimated the population in the reserve was 1,856 (95% CI 951–3710), which is 28 times as many. Yet Galea (2023) reports the result with horses to be *'implausible'* without quoting any other evidence or any kind of analysis. This is not scientific.

It is common in human medical research for there to be an interaction with every human subject, something virtually unknown in ecology. A pasture ecologist, for example, cuts and dries vegetation samples from quadrats whose area might represents one millionth of the vegetation patch about which the ecologist will make descriptive statements and predictions. An ecologist studying insect species may never see 99.999% of the individuals of the population under study. Thus the design and practice of sampling is a core activity in ecology, but less central to medical research. Perhaps that is why a medical statistician made this mistake.

B8 Width of the confidence intervals – p. 15

The report points to the width of the 95% Confidence Interval for the 2022 survey i.e. 14,501 to 23,535 as a reason the population estimates from horse surveys are *'unreliable'*.

This result was better than the owners of the survey had intended. Their requirements for precision were stated in advance (Table 1 in Cairns 2022) and were bettered in all survey blocks (Table 6 in Cairns 2022).

How can it be that a level of precision that is better than what the experienced people responsible for the survey had paid for, is regarded by Galea as unacceptable?

Wildlife surveys only rarely provide tight precision and to improve precision is often impossible or at best inordinately expensive. Many component measurements are being combined, including the height of the aircraft, its position, the distance from the transect to the horses, and the distribution of horses between transects. In addition, the animals move in and out of view and during the course of the survey there may be births, deaths, immigration and emigration. These potential sources of errors magnify, resulting in wider confidence intervals than would be achievable in some other circumstances, such as lab-based research.

The reference given to support Galea's opinion that the confidence intervals are too wide (Bonham 1989) is actually a web page about the beauty of racehorses and does not contain any such statistical comment.

Please note that precision is expressed in the survey report (Cairns 2022) in terms of the Coefficient of Variation (CV%). This is the normal metric for the purpose and is widely used. Galea's use of the 95%CI as a percentage of the mean is one I have not seen before. It results in a higher percentage than the CV.

C1 Implausible population increases – p. 16

Among brumby activists there is a persistent idea that some of the rates of population increase observed in the wild are impossible. Doubt about the population growth leads to the thought that the population estimates must be wrong. Such observers sometimes point out that their well fed mares only produce a foal every second year. Even if the population comprised an equal number of male and female breeding adults, that would corresponds to 25% increase per year so real populations would increase at lower rates.

Early research on the Kosciuszko feral horses produced an estimate of 22% for the intrinsic rate of increase of horses (Dawson 2002, p. 70). This has been variously misquoted as a maximum population growth rate (PGR) for horses, but the two are different. (Confusion is not helped by a commonly used representation of the intrinsic rate of increase as r_{max} or r_m). A population grows at the intrinsic rate of increase for that species if it has a balanced sex and age distribution, and is not limited by food or other resources, or externally imposed mortality such as harvesting or predation (Caughley 1977). The details of this definition are important.

Most populations, most of the time, have PGR close to zero (Caughley 1977; Hone 1999, 2012; Sibly and Hone 2002), much lower than the intrinsic rate of increase for the species, but population growth rates higher than the intrinsic rate of increase are possible in unusual cases, for example a female biased population can grow faster than the intrinsic rate of increase and so can a population that is biased toward the maximum breeding age. Farmed animal populations normally exhibit both features. So PGRs greater than Dawson's (2002) estimate of 22% for horse r_m are possible and have been observed. Wild horse population growth rates up to 39% have been observed by researchers (Scorolli and Lopez-Cazorla 2010).

In addition, horses move into and out of the areas counted, for example between KNP and parks in Victoria. Changes in the estimated population size that are greater than 22% have been partly attributed to such movement (Cairns 2022). The extent and frequency of such movement has not been researched, so unfortunately there is no way to determine how much of the large increases in estimated population size are due to breeding, how much to immigration, and how much to counting error. In the absence of that research, Galea's (2023) criticism is unfounded.

C2 Movement of horses – p. 17

The report says that because horses are capable of crossing the line bounding the counted area, *'the possibility of double counting cannot be eliminated'*

This is illogical. Observers were not counting the same area more than once so there is no question of so called *'double counting'* due to local movement of horses. If animals move into the counted area before the day of counting they will be included. If they move out before the count, they will not be included. Animals whose home ranges straddle the boundary of the counted area contribute to the inherent variability between successive wildlife counts by being inside the counted area in some years and outside it in others.

The report also says about the Kosciuszko horses that *'a true count cannot be determined'*. Here Galea may have begun unwittingly to uncover an important concept. The important idea is to accept that estimating the size of a wild animal population is not analogous to normal counting (of human research subjects, for example, or farm animals in a yard) where the exact number of counted objects can be determined.

A wild population is more like a river flowing constantly. While the count is underway and after it has been completed, animals are dying, and being born, and moving into and out of the area, and these changes are unseen by the person doing the counting. The exact number of animals in the population at any instant is unknowable. Even the geographic extent of a population at a particular time is usually impossible to know exactly, except perhaps on an island or in artificial settings.

Ecologists almost never determine an exact number for wildlife population size but an exact number is not required. What is needed is an estimate of population size that is good enough for the purpose for which the count was done.

C3 Foals and joeys – p. 17

The report claims that the surveys provide no counts of foals. First, this is a gratuitous claim because separate counts of foals have never been shown to be necessary. There are numerous examples of vertebrate species being managed successfully without separate counts of juveniles. But in any case, foal counts are plainly evident in the reports, for example in Cairns (2022) they are mentioned in the Summary, the Methods on p. 16, in Table 7 that occupies all of p. 27, and their discussion occupies almost an entire page in the Results and Discussion (p. 26). The count of foals goes above and beyond what is required for the management of the Kosciusko horses and is so difficult to miss that it leaves the reader scratching their head how this claim came to be made.

C3 is yet another mistaken claim by Galea (2023).

CONCLUSION

Galea (2023), the report named in the title of this commentary, is not a reliable scientific document because many of its criticisms prove on closer inspection to be mistaken, based on a misreading of the reports being criticized, or based on a misunderstanding of ecological methods. In some cases, criticisms are repeated under a different title, creating a false impression of the number of problems found.

The criticisms of Helicopter Line Transect Distance Sampling to estimate the population abundance of feral horses in KNP are not supported by either evidence, such as references to scientific literature comparing superior alternative methods, or by published results of alternative counts in KNP using well understood methods of abundance estimation that are recognised in the scientific literature. No data are provided and there are very few references to the vast ecological literature on wildlife counting.

There is an established body of scientifically credible material available on the counting of the feral horse population in Kosciuszko National Park (Walter 2003; Walter and Hone 2003; Montague-Drake 2005; Laake et al 2008; Dawson 2009; Dawson and Hone 2012; Cairns 2019, 2020, 2022). Galea (2023) adds nothing either credible, or valuable, to this subject.

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REFERENCES

Buckland, S.T., Anderson, D.R., Burnham, K.P.., Laake, J.L., Borchers, D.L. and Thomas, L. (2001). Introduction to Distance Sampling: Estimating Abundance of Biological Populations. (Oxford University Press: London.)

Buckland, S.T., Anderson, D.R., Burnham, K.P.., Laake, J.L., Borchers, D.L. and Thomas, L. (2004). Advanced Distance Sampling: Estimating Abundance of Biological Populations. (Oxford University Press: London.)

Cairns, S. (2019) Feral Horses in the Australian Alps: the Analysis of Aerial Surveys Conducted in April-May, 2014 and April-May 2019. A report to the Australian Alps Liaison Committee. Available from https://theaustralianalps.files.wordpress.com

Cairns, S. (2020). The results of a survey of the wild horse populations in the Kosciuszko National Park, October-November. Available from https://theaustralianalps.files.wordpress.com

Cairns, S. (2022). A survey of the wild horse population in Kosciuszko National Park, November 2022. Report to the National Parks and Wildlife Service, NSW. Available from https://www.environment.nsw.gov.au/research-and-publications/publications-search/a-survey-of-the-wild-horse-population-in-kosciuszko-national-park

Cherubin, RC., Venn, SE., Driscoll, DA., Doherty, TS., and Ritchie, E G. 2019. Feral horse impacts on threatened plants and animals in sub-alpine and montane environments in Victoria, Australia. *Ecological Management and Restoration* **20**(1) 47–56. https://doi-org.ezproxy.canberra.edu.au/10.1111/emr.12352

Commonwealth of Australia (2019). Australia's Strategy for Nature 2019–2030. Commonwealth of Australia. 38pp. Available from www.australiasnaturehub.gov.au Accessed 8/6/23.

Dawson, MJ. (2005). The Population Ecology of Feral Horses in the Australian Alps: Management Summary. Australian Alps Liaison Committee Archive. Available at: The population ecology of feral horses in the Australian Alps management summary | Australian Alps National Parks (wpcomstaging.com) accessed 7/3/21.

Dawson, MJ. (2009). 2009 aerial survey of feral horses in the Australian Alps. A report to the Australian Alps Liaison Committee.

Dawson, M.J. and Hone, J. (2012). Demography and dynamics of three wild horse populations in the Australian Alps. Austral *Ecology* **37**(1), 1–13.

Driscoll DA., Worboys GL., Allan H., Banks SC., Beeton NJ., Cherubin RC., Doherty TS., Finlayson CM., Green K., Hartley R., Hope G., Johnson CN., Lintermans M., Mackey B., Paull DJ., Pittock J., Porfirio LL., Ritchie E.G.., Sato CF., Scheele BC., Slattery DA., Venn S., Watson D., Watson M., Williams RM. 2019. Overview: Impacts of feral horses in the Australian Alps and evidence-based solutions. *Ecological Management and Restoration* **20**(1) 63–72. https://doi-org.ezproxy.canberra.edu.au/10.1111/emr.12357

Dyring, J. 1990. The impact of feral horses (Equus caballus) on sub-alpine and montane environments in Australia. MSc thesis, University of Canberra, Australia.

Eldridge DJ., Travers SK., Val J., Zaja A., and Veblen KE. (2019). Horse Activity is Associated with Degraded Subalpine Grassland Structure and Reduced Habitat for a Threatened Rodent. *Rangeland Ecology & Management* **72**(3), 467-473.

Glass, R., Forsyth, DM., Coulson, G. and Festa-Bianchet, M. (2015) Precision, accuracy and bias of walked line-transect distance sampling to estimate eastern grey kangaroo population size. *Wildlife Research* **42**, 633–641.

Galea C., (2023). Independent biostatistical report on the Brumby population in the Kosciuszko National Park. Unpublished report (18pp) circulated on social media by brumby activists and provided to state and federal politicians responsible for decisions about management of feral horses. Available at https://meetourhorsemeat.com/wp-content/uploads/2023/05/Independent-Biostatistical-report-into-the-counting-of-wild-horses-Claire-Galea.pdf Accessed 8/6/23.

Hone, J. (1988). A test of the accuracy of line and strip transect estimators in aerial survey. *Australian Wildlife Research* **15**, 493–497.

Hone, J. (1999). On rate of increase (r) patterns of variation in Australian mammals and the implications for wildlife management. *Journal of Applied Ecology* **36**, 709-718.

Hounsome, TD., Young, RP., Davison, J., Yarnell, RW., Trewby, ID., Garnett, BT., Delahay, RJ., and Wilson, GJ. (2005). An evaluation of distance sampling to estimate badger (*Meles meles*) abundance. *Journal of Zoology* **266** (1) 81–87.

Laake, J., Dawson, MJ. and Hone, J. (2008). Visibility Bias in aerial survey: mark-recapture, line-transect or both? *Wildlife Research* **35**: 299–309.

Linklater W. and Cameron E. (2002). Escape behaviour of feral horses during a helicopter count. *Wildlife Research* **29**: 221–224.

Montague-Drake, R. (2005) Results of Aerial surveys to determine wild horse densities and abundance in northern and southern Kosciuszko National Park: a report by the Reserve Conservation Unit, Parks and Wildlife Division.

Schulz M., Schroder M. and Green K. (2019). The occurrence of the Broad-toothed Rat *Mastacomys fuscus* in relation to feral Horse impacts. *Ecological Management and Restoration* **20**(1) 31–36.

Scorolli, AL. and Lopez-Cazorla, AC. (2010). Demography of feral horses (*Equus caballus*): a long-term study in Tornquist Park, Argentina. *Wildlife Research* **37:** 207–214.

Sibly, RM. and Hone, J. (2002). Population growth rate and its determinants: an overview. *Philosophical Transactions of the Royal Society London B*. **357**,1153–1170.

Thomas, L., S.T. Buckland, E.A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P.. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* **47**: 5–14. DOI: 10.1111/j.1365-2664.2009.01737.x

Walter, M. (2002). 'The Population Ecology of Wild Horses in the Australian Alps.' PhD Thesis (University of Canberra: Canberra.)

Walter, MJ. (2003). The effect of fire on wild horses in the Australian Alps National Parks. A report prepared for the Australian Alps Liaison Committee, unpublished.

Walter, MJ. and Hone, J. (2003). A comparison of 3 aerial survey techniques to estimate wild horse abundance in the Australian alps. *Wildlife Society Bulletin* **31**, 1138-1149

APPENDIX: Horse population estimates in KNP and how calculated

Date	Area surveyed	Report	Size of area surveyed (sq km)	Horse Popn estimate	Lower 95% Conf Limit	Upper 95%Conf Limit	Horse Popn in KNP (calc from AANP survey as needed)	Upper 95%CI for KNP	Lower 95% CI for KNP	How KNP portion calculated
Mar-01	AANP	Walter and Hone 2003	2,789	5,200	1,979	8,421	3,000	1,858	1,858	Kosciuszko NP component estimated by Walter (2005)
Apr-03	AANP	Walter 2003	2,717	2,369	3,937	3,937	1,367	905	905	Same proportional adjustment as above (0.58)
Jun-05	KNP	Montague-Drake	1,052	1,357	759	1,955	1,357	598	598	No change necessary
Apr-09	AANP	Dawson 2009	2,860	7,679	CV 25.4%		4,684	2,332	2,332	Adjusted by the proportion of horse groups counted in Kosciuszko NP, given in Dawson (2009 Table 1), ie 0.61.
May-14	AANP	Cairns 2019	7,443	9,187	7,484	11,595	5,604	1,984	1,984	Adjusted by the proportion of horse groups counted in Kosciuszko NP, given in Cairns (2019 Table 3), ie 0.61 excluding the Bago Maragle block and half of the Byadbo-Victoria count.
May-19	AANP	Cairns 2019	7,443	25,318	CV 12.3%		19,242	4,581	4,581	Adjusted by the proportion of horse groups counted in Kosciuszko NP, given in Cairns (2019 Table 3), ie 0.76 excluding the Bago Maragle block and half of the Byadbo-Victoria count. Confidence Limits estimated from CV.
Oct-20	KNP	Cairns 2020	2,673	14,380	8,798	22,555	14,380	8,175	5,582	No change necessary
Oct-22	KNP	Cairns 2022	2,675	18,814	14,501	23,535	18,814	4,721	4,313	No change necessary

AANP = Australian Alps National Parks; KNP = Kosciuszko National Park

<u>Original Reports of horse counts in KNP</u>

Cairns, S. (2019). Feral Horses in the Australian Alps: the Analysis of Aerial Surveys Conducted in April-May, 2014 and April-May 2019. A report to the Australian Alps Liaison Committee. Available from https://theaustralianalps.files.wordpress.com

Cairns, S. (2020). The results of a survey of the wild horse populations in the Kosciuszko National Park, October-November. Available from https://theaustralianalps.files.wordpress.com

Cairns, S. (2022). A survey of the wild horse population in Kosciuszko National Park, November 2022. Report to the National Parks and Wildlife Service, NSW. Available from https://www.environment.nsw.gov.au/research-and-publications/publications-search/a-survey-of-the-wild-horse-population-in-kosciuszko-national-park

Dawson, M.J. (2009). 2009 aerial survey of feral horses in the Australian Alps. Report prepared for the Australian Alps Liaison Committee. Available from https://theaustralianalps.wordpress.com

Dawson, M.J. and Hone, J. (2012). Demography and dynamics of three wild horse populations in the Australian Alps. Austral Ecology 37(1), 1–13.

Dyring, J. 1990. The impact of feral horses (*Equus caballus*) on sub-alpine and montane environments in Australia. MSc thesis, University of Canberra, Australia.

Montague-Drake, R. (2005) Results of Aerial surveys to determine wild horse densities and abundance in northern and southern Kosciuszko National Park: a report by the reserve conservation unit, Parks and Wildlife Division.

Walter, M.J. (2003). The effect of fire on wild horses in the Australian Alps National Parks. A report prepared for the Australian Alps Liaison Committee. Available from https://theaustralianalps.files.wordpress.com.

Walter, M. J. and Hone, J. (2003). A comparison of 3 aerial survey techniques to estimate wild horse abundance in the Australian alps. Wildlife Society Bulletin 31, 1138-1149