
# The Number Game: Counting Kangaroos

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**Abstract:** Well over one million kangaroos are shot each year in New South Wales, around half of them for the kangaroo 'industry', a harvest underpinned by the annual supply of population estimates sustaining the widespread impression that kangaroos are a 'pest', 'in plague proportions'. Each year these figures, added to historical tables (typically from 1990 onward), are published as part of the state's Quota Report, upon which the following year's shooting quota is based. Drawn from aerial surveys, these estimates are nevertheless characterised by the persistent incidence of extraordinary annual population growth rates, well in excess of biological possibility. This paper interrogates these anomalies and considers them in the context of actual reproductive capacity of kangaroos and other factors (male-to-female ratios, infant survival rates, etc.) determining a population's ability to regenerate. It suggests that the sudden and extraordinary elevations in population registered in the tables are less the result of massive kangaroo migrations, as some suggest, than of inflationary systemic biases at once reflecting and promulgating erroneous assumptions – a myth – of hyperfecundity and of the kangaroo as a 'boom' species. Considerable confusion surrounds the regenerative capacities of kangaroos. The paper attempts to clarify this issue with calculations demonstrating that, even in a very good year, a kangaroo population is unlikely to grow at a rate much exceeding 12%, let alone a rate of

200, 400, or even 500% as official tables sometimes state. Figures of the actual 'take' (kill count) over the last decade, it argues, tell a very different story, and suggest not abundance but populations in serious decline.

**Keywords:** hyperfecundity, kangaroo, migration, population surveys, population estimation, quota system, reproductive capacity, system bias, wild animal harvest

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Each year well over a million kangaroos are shot in New South Wales,[1] around half of them harvested for the kangaroo industry. This slaughter is underpinned by assurances from government and industry alike that the state's macropods (kangaroos) are abundant, and complaints from the pastoral industry that kangaroos are a 'pest', 'in plague proportions'. Yet for some time now – at the *same* time – travellers over the Western Plains have reported sighting few if any kangaroos, and shooters themselves complain of having to travel so much farther to find their targets that their occupation is becoming unviable.[2] A 2020 government report indicated that in several harvesting zones shooting had been temporarily suspended because kangaroo numbers had fallen below the danger threshold of 1.2 per square kilometre.[3] In 2019 in the Cobar Kangaroo Management Zone (40,000km$^2$ in the centre of the state), that report stated, a government survey registered only one eastern grey kangaroo per five square kilometres, while in 2020 in the Tibooburra zone eastern grey kangaroo density had fallen so low one would be lucky to find one kangaroo in ten square kilometres.[4] A clear discrepancy here. How might such a situation have come about?

Much argument on the part of kangaroo advocates and 'harvesters' alike is devoted to numbers, and considerable confusion surrounds them. In large part this is because, while certain kangaroo population figures are hotly asserted as fact by either party, and while there are disconcerting signs current numbers may be perilously low, no one really knows what the 'true' numbers are. Indeed the 'true' numbers have been until this point, and will very likely be for some distance into the future (when, hopefully, we have more accurate counting methods than at present), almost impossible to determine.

In order to maintain its licence to export kangaroo products – skins, used largely for shoes, and meat for human and non-human consumption – the New South Wales (NSW) government is nevertheless compelled to provide, in a report to the Australian government, a yearly estimate of kangaroo populations (eastern grey, western grey, red kangaroo, wallaroo) targeted in the state and, based on those estimates, to suggest an upper limit (the *quota*) to the number of each species it proposes to shoot in that year to supply those markets. These reports – Quota Reports – contain current and historical tables of population estimates, charting fluctuations in population, quotas, and the 'take' (actual numbers killed) for each species involved.

A recent NSW parliamentary inquiry into the health of the state's macropod populations was alerted to various anomalies in these tables, in particular the pervasive occurrence of population increases which appear to be well beyond biological possibility. The same inquiry exposed widespread confusion concerning the nature and operation of population surveys, the processing of survey data, and the capacity, biological and otherwise, of kangaroo populations to recover after outbreaks of disease, periods of drought, or other natural and unnatural disasters.

This paper lists and interrogates some of the abovementioned anomalies, examining possible explanations for the sudden precipitous rises in population, and locating areas where, to properly assess the size and health of the state's kangaroo populations, the public may need further information and explanation than currently provided. In the process, it attempts to clarify some of the confusion concerning population survey and estimation processes, and the biological capacity of kangaroo populations to increase.

## The System: Surveys and Estimations

Kangaroo populations fluctuate. They grow, in a run of good years, and decrease, often quite dramatically, in a run of bad. A string of two or three hot, dry years can devastate kangaroo numbers. Although this has doubtless always been the case, it's become precipitously so, and the overall situation has worsened significantly, as rangelands have been more and more depleted or

rendered more and more inaccessible by human incursion and partitioning (roads, fences). In a run of good years one can expect that commercial kill quotas will be larger, in a run of bad that they would decline.

The Australian government maintains formal oversight of these fluctuations, and of the kangaroo industry nation-wide. It has determined, for example, that no more than 17.5% of the red kangaroo population, and no more than 15% of other species, should be commercially 'harvested' in any state, or zone of that state, in any calendar year. In addition to ratifying quotas suggested by the individual states, the Australian government collates – and publishes – population estimates from around the country.

These collated estimates should not be seen as *national* estimates. While we might make an educated guess at such things, national figures *per se* do not exist; at least, not in any form readily available to the public. What we *do* have are totals of figures from 'participating states': that is, from states that have agreed to be part of the harvesting program and so to meet Australian requirements (chiefly to draw up kangaroo management plans, and monitor and report on populations and shooting to ensure sustainability of the species is not compromised[5]) to be allowed to supply kangaroo products to international markets.

For some time now, those participating states have been Queensland, New South Wales, South Australia, and Western Australia. Tasmania and Victoria have recently joined them. The Australian Capital Territory and Northern Territory do not participate in this program, although it should be noted that the ACT does conduct an annual kangaroo slaughter.[6] (The ACT government has estimated there are upwards of 200,000 eastern grey kangaroos in the territory. Non-government estimations are far lower. Since the ACT slaughter is not 'commercial', let alone for the international market, no figure is included in the collated total. No annual estimates are readily available for the Northern Territory.)

Population figures from participating states, I might reiterate, are themselves estimates. These estimates may give an *indication* of what the population figures may be for any given state for any given year, but they are not exact, for numerous reasons.

The kangaroo is not a domesticated animal. To supply any potential 'industry' with kangaroo products, kangaroos must be shot in the wild, no viable way as yet having been discovered in which they may be farmed. The areas, within each participating state, where the state and Australian governments determine kangaroos may be professionally shot, are divided into Kangaroo Management Zones (KMZs). These zones cover very large areas. In NSW, for example, two of these zones (Broken Hill and Griffith) are each greater than 90,000 square kilometres (somewhat larger than Ireland), and the other eleven average nearly 40,000km$^2$ (39,576). Overall, in NSW, KMZs cover 81.69% of the state.

The basic data from which population estimates are determined is gathered through aerial surveys, conducted late (usually between July and September) in the years in which they occur. An aircraft flies low over a portion of a zone, sweeping methodically back and forth so as to cover as much of the area as deemed necessary to provide a reliable indication of overall population. Stephen Jackson and Karl Vernes (2010) give a useful idea of this process.[7] 'The fixed-wing aircraft technique', they tell us:

> is known as strip transect sampling. Two trained observers, travelling at 185 kilometres per hour at about 76 metres (250 feet) above the ground, count the animals within a 100- or 200-metre wide area on the ground that is delineated by streamers or fibreglass rods attached to the wing struts on either side of the aircraft and trailing parallel to the fuselage. The observers count in 97-second units, with a seven-second break in between counts, giving a sampling unit of half or one square kilometre. (176/77)

The problems inherent in this process are daunting. Not only is there the speed of the plane, and that of the kangaroos themselves, leaping off in unpredictable directions, but in general kangaroos will be resting during the day, and for preference will do so in the shade of trees, which one can imagine is not the easiest place to see them from the air. It may be that the sound of an approaching aircraft will scare and drive them into the open, but it also may be that it doesn't, or does the opposite. Although, since kangaroos are crepuscular, survey flights are done

in the early morning and late afternoon, when kangaroos are most active, it's fair to assume – indeed is a fundamental assumption of these surveys – that the number of kangaroos counted from the air is not the number of kangaroos on the ground.

In order to compensate for kangaroos thus missed, a *correction factor* is applied to the number of kangaroos actually seen. A factor of (multiplication by) 2.0, for example, would mean that, for every kangaroo seen, it is assumed there is one further kangaroo *not* seen; a correction factor of 3.0 would suggest that, for every kangaroo seen, there are a further two who have not been seen. The correction factor varies according to terrain. It will be harder to count kangaroos in some places – more deeply wooded or more rugged areas – than in others, and in some areas quite impossible. Depending upon terrain and other factors, seven kangaroos seen, when it comes to setting a figure on paper, may become fourteen, or twenty-one, etc. These, one might argue, are therefore kangaroos largely on paper; it can't be definitively established whether or not they are kangaroos in fact. Although the standard correction factor appears to be 1.85, factors as high as 10 have been recorded.[8]

Ideally, of course, an entire KMZ would be surveyed. Whether because aerial surveying is expensive and the kangaroo 'industry' is not exactly a multi-billion-dollar concern, however, or simply because it is common practice in such estimations,[9] *a very small proportion only* (a 'sample' [or 'replicate' in statistics]) of each KMZ is surveyed.

The number of kangaroos counted in this sample area, adjusted by the determined correction factor, is then – as per accepted practice – extrapolated to the rest. So it is, for example, that the 508 wallaroos counted in the Northern Tablelands survey area in 2019, adjusted by a correction factor of 1.85 and with certain minor accommodations made for varying terrain, etc.,[10] became an estimated wallaroo population of 296,555 for the 48,000 square kilometre Northern Tablelands Kangaroo Management Zone, *a figure 583 times larger* (as some commentators have pointed out) than the number of wallaroos *actually sighted* in a survey of little more than one quarter (0.28) of one percent of the total area of the zone.[11] Whether such a minute sample can be seen as adequately representing the area as a whole is an open question.

The *frequency* with which an area is surveyed is a further factor determining the reliability or otherwise of population estimates. This, too, depends upon resources and government policy. In NSW the six zones where terrain is less open and counts are done by helicopter[12] are surveyed triennially; those more open, 'rangeland' zones where they are done from fixed-wing aircraft are surveyed annually. There are, as we shall see, problems with either method.

## Inconsistencies and Anomalies

In tables produced for zones surveyed triennially, the estimated population figure from the survey year is simply reproduced for the two years following. The results for a zone surveyed in 2016, for example, appear as the population estimate for that zone for 2016, 2017 and 2018. The zone is re-surveyed in 2019 and a new figure appears for 2019, 2020 and 2021.

In actuality, of course, the kangaroo population itself does not always remain conveniently stable for three consecutive years. This need not be particularly significant if the population exhibits only minor fluctuations over that time, but if it drops, as it can do rapidly during drought, quotas (in what I am tempted to call the 'quota lag') can be considerably higher than could be argued for the population that is 'actually' there for much of the time to which the quota applies.

An example, from table 43 of the *2021 Quota Report*, concerning the eastern grey kangaroo population of the Central Tablelands North KMZ:

Table 1: Central Tablelands North KMZ, eastern grey estimates (extract)

| Year | Population | Density | % Change | Quota | % Population |
|---|---|---|---|---|---|
| 2017 | 1,728,200 | 74.54 | 45 | 179,040 | 15.0 |
| 2018 | 1,728,200 | 74.54 | 45 | 259,230 | 15.0 |
| 2019 | 1,728,200 | 74.54 | 45 | 259,230 | 15.0 |
| 2020 | 777,350 | 33.53 | –55.0 | 259,230 | 15.0 |
| 2021 | | | | 116,603 | 15.0 |

This KMZ was surveyed late in 2017. The next survey (2020) found that, owing to the worsening drought, the eastern grey kangaroo population had dropped by 55%. This means, in effect, the quota applicable for 2020 was more than double that determined by the government itself as the maximum allowable (33.3% rather than 15%) and appears to contradict the very table in which we find it, since this table tells us that the quota *for that year* represents 15% of the population. Given that the drought had been steadily worsening, moreover, it's surely conceivable that, *had* there been surveys in the intervening years, the population might well have been found to be falling *through* 2018, 2019 and the first nine months of 2020, and that the quotas set for these years, too, would in actuality have represented more than 15% of the KMZ's eastern grey population in each of these years and have allowed, potentially, an unsafe number of kangaroo killings to have taken place, exacerbating the population decline.

It would seem logical, considering such possibilities, to have certain cues – climatological, for example, and/or observational (on-the ground reports from the community or designated officers concerning impacts upon macropod welfare) – set into place that, when triggered, would lead to interim adjustments in the quotas. But, as we shall see, the wind blows both ways. On the one hand kangaroo welfare is interpreted as preserving the lives of

individuals; on the other there appears to be a belief among pastoralists and kangaroo management that, to prevent kangaroo suffering in times of drought, there should be ever larger numbers routinely shot (and, presumably, the largest possible quotas, as stimulus).[13] It goes without saying the latter option also suits the short-term interests of commercial exploitation.

It is hard to see how this quota lag, exaggerated in zones surveyed triennially, is not also a problem, albeit and admittedly on a lesser scale, in zones surveyed annually. A dramatic case can be found in table 23 of the same *2021 Quota Report*, concerning the eastern grey kangaroo population of the Cobar zone where, although this table states that for 2017 the quota was 15% of the population, and for 2018 was 12.1%, it was arguably somewhat higher (approximately 33% and 27% respectively, at least for the last three months of those years).[14] Given the devastating impact of the drought in that area at that time, those quotas, *had they been being met*, might well have occasioned, or at least hastened, the regional extinction of the species.

Table 2: Cobar KMZ, eastern grey estimates (extract)

| Year | Population | Density | % Change | Quota | % Population |
|---|---|---|---|---|---|
| 2016 | 405,079 | 10.0 | –17.7 | 73,831 | 15.0 |
| 2017 | 184,069 | 4.5 | –54.6 | 60,762 | 15.0 |
| 2018 | 81,391 | 2.0 | –55.8 | 22,329 | 12.1 |
| 2019 | 7,317 | 0.2 | –91.0 | 0 | 0.0 |
| 2020 | 44,208 | 1.1 | 504 | 0 | 0 |

The decline in eastern grey numbers registered here is alarming, the drop of 91% from 81,391 in 2018 to 7,317 in 2019 so precipitous one cannot but think the species is already in population collapse, particularly if one considers a correction factor has very likely been added and that the

number of eastern grey kangaroos *actually seen* by the survey crew, had that alone been extrapolated to the wider zone, might have led to closer to 4,000 kangaroos in total.

Just as extraordinary, after such a precipitous fall, is the *recovery* tabled in the year following, an increase in the population of 504%. Such an increase is biologically impossible. On the one hand it would mean that every single female eastern grey kangaroo in this zone had had at least nine joeys that year, and on the other, as I'll shortly explain, the absolute upper limit at which a population of kangaroos is able to increase its numbers, is, in the very best of years, around 15% – something which, and in the face of the apparent defiance of its own tables, the NSW government itself seems to have accepted in setting 15% as the maximum amount a population might be 'harvested' each year without compromising its sustainability.

In this particular case there may be an explanation. We have seen already, from a survey of barely one quarter of one percent of a 48,000 $km^2$ zone, how a mere 508 wallaroos can become 296,555 when extrapolated to the rest of the zone. The Cobar zone is 40,419 $km^2$ overall. It would take little more than a handful of additional kangaroos to be actually sighted in the survey (an extra pod or two straying into the sample area) to bump up a figure of 7,317 to 44,206.

If, in this instance, on the grounds of the very small size of the population, simple statistical aberration might explain what biological possibility can't,[15] biological impossibility stares us in the face from the majority of the dramatic leaps in population with which the NSW historical tables are littered and where the base populations are considerably larger. To restrict ourselves to recent history, there are, for example, the rise of 426% in the Tibooburra KMZ grey kangaroo population in 2015 (from 44,669 in 2014, to 234,927) [table 17], the rise of 153% in the Tibooburra red kangaroo population in 2020 (from 79,346 in 2019, to 200,465)[table 16], and the rise in the Broken Hill KMZ eastern grey population of 164.4 % in 2013 (from 221,803 in 2012, to 586,534) [table 19].

To avoid any suspicion of cherry-picking, let me approach the matter differently.

Of the last twenty years (2001-2020), in the Narrabri KMZ, there have been nine years in which the number of grey kangaroos declined, and eleven years in which it rose. Of these

eleven years, there were seven in which it rose by a percentage beyond biological capacity. In the last twenty years (2001-2020), in the Broken Hill KMZ, there have been twelve years in which the number of grey kangaroos declined, and eight years in which it rose, in seven years of which it did so beyond biological capacity. In the Lower Darling KMZ in this same period there were nine years in which the grey kangaroo population declined, and eleven in which it rose. In eight of those eleven it did so by more than 20% (25.4, 99, 62.1, 134.6, 109.7, 57.1, 32.3, and 34.8): i.e., well beyond biological capacity. This pattern is repeated in all the annually surveyed Western Plains kangaroo management zones, and in most of those surveyed triennially.

If biology cannot account for these leaps in population, what might? At a recent NSW parliamentary inquiry, Department of Planning, Industry & Environment (DPIE) officers supposedly responsible for kangaroo management were asked just this question and, after consulting with experts, suggested these changes were owing to *migration*, though when pressed admitted they had a knowledge gap in this regard.[16]

## Migration

Mass movements of kangaroos from one part of the state to another would certainly explain sudden large population increases in a KMZ (and presumably *de*creases in neighbouring KMZs). A significant problem with this explanation, however, is that *other* experts have said eastern grey kangaroos and wallaroos do *not* migrate. They might, in times of drought, forage further than they would normally, but in general, and particularly in good seasons (when they will have no reason to range further), they keep to a home range.[17]

Had migration truly been a factor in the minds of the DPIE or of those contractors who make and frame their surveys, we might expect it to have been mentioned in quota reports. While there is, in the *2021 Quota Report*, a mention of 'the movement of kangaroo between zones', it is only the once and to do specifically with variations in 2015 and 2016 figures and the introduction of a new method of survey and analysis. In the entire report there is not one mention of migration *per se*.

That 'new method' is MRDS: Mark Recapture Distance Sampling. Mark-recapture, the report tells us, 'derived from the aerial survey, where two observers independently count animals along the same transect on both sides of the aircraft, is used to account for the bias in detection probability between observers'. This does not seem so much a 'new method' as a rather simple refinement of the old one. To call it MRDS is misleading.

MRDS, as it is more generally understood, is a process in which a certain number of individuals from the population being surveyed – a dozen, let's say – are captured and marked in some way that will not affect their social mobility. They are then released and allowed to disperse into the wider population. After a certain amount of time a second group of individuals from that population is randomly captured (i.e., regardless of whether they are marked or not). The number of marked individuals in this second group is then, by way of the formula $N = (MxC)/R$, used to calculate the size of the overall population.[18]

Two fundamental assumptions of this method are that there be *no migration from or into* the area whose population is being assessed (any inward migration would significantly inflate the estimates), and that there be no mortalities in the target population during the assessment period. It would have been strange to have introduced such a method, as the DPIE say they introduced theirs (2016), when a new and long drought was setting in and mortality in the target population was becoming more and more of a factor. And stranger still, surely, given that it is essential for the effective operation of MRDS that there be no migration from or into areas being assessed, that they would claim to have introduced MRDS at all, if they suspected migration were any kind of factor in the sudden dramatic elevations of population we're discussing.[19]

Some of the confusion here might be semantic. Before we entirely dismiss it as a possibility, we might ask what, in this context, 'migration' might mean. Eastern grey kangaroos may not 'migrate', but they do move about their range in search of forage, and in times of drought (or flood, or fire, etc.) will doubtless range further. How far can you range before it's called migration? And, once you've migrated, can you move back again? (It seems to me any kangaroos 'migrating' for forage are likely to 'home' if they can when matters improve.) And

kangaroos aren't necessarily going to observe human borders, human zones. What of those whose range covers territory in more than one zone? Are they 'migrating' as they move from one part of their range to another? Red kangaroos, some scientists tell us, *do* migrate. But is 'migration' the right word here? Mightn't they, in their arid zones, just have larger ranges, and/or a need or propensity to roam farther for forage?

Without doubt a careful study of the movements of key macropod species in NSW would be most useful, if also quite an undertaking. But we are viewing, in the available tables, some very dramatic elevations in NSW population estimates from one survey to the next. And in most cases, it's hard to see how these rises could be occurring through external supplementation. Any suggestion that mass migrations across state boundaries – from Victoria, South Australia, Queensland – might be responsible would have to explain how very large numbers of kangaroos could have crossed the Murray or the Darling River, the Dog Fence, the Great Dividing Range, or the Dumaresq and Macintyre Rivers. Not impossible, I grant – there are some large gaps, kangaroos can be good swimmers, and the rivers do sometimes run dry – but to all intents and purposes the NSW killing zones are something of a closed system. There may be some problems with how that system is currently being assessed, however, and yes, movement may be one of them. It may, that is, explain some of the massive leaps in population we find in the tables, but this does not (/need not) mean that the numbers of kangaroos thus indicated are actually there.

***An Out-take***

I'd like to consider an out-take from the *2021 Quota Report*, from the Lower Darling KMZ red kangaroo population estimates (table 20) for 1990-2020, the first a mere two rows, for 2018 and 2019:

Table 3: Lower Darling KMZ, red kangaroo estimates (extract)

| Year | Population | Density | % Change | Quota | % Population |
|---|---|---|---|---|---|
| 2018 | 307,619 | 5.4 | 6.3 | 49,195 | 17.0 |
| 2019 | 691,119 | 12.2 | 124.7 | 52,295 | 17.0 |

These rows present us with a huge jump in numbers, impossible biologically and particularly surprising in a population being surveyed, in a year of rapidly worsening drought, in order to set a quota for what must surely have been expected to be an even worse year. If we're unable to explain this remarkable increase – 2019's is the highest red kangaroo population recorded in the thirty years covered by the table – then we must assume either the figure for 2019 is wrong, or the figure for 2018 is wrong, and that, if *either* figure can be so wrong, there's something askew in the estimation process itself.

*Could* migration be a factor? In a relatively closed system, such as I've suggested we find in New South Wales, we might expect a sudden dramatic rise in population in one zone to be accompanied by a commensurate decline in a neighbouring zone. The Lower Darling KMZ is bordered in the south by the state of Victoria, in the east by the Griffith zone, in the north by the Broken Hill zone, and in the west, its shortest border (from the Murray half-way up toward the Dog Fence), by the state of South Australia. Migration from Victoria is effectually blocked by the Murray River. In 2018 the Griffith KMZ had one of its *lowest* counts of red kangaroo: even if every one of its reds had migrated westward it wouldn't have been enough to explain the 2019 Lower Darling figure. Broken Hill's population of red kangaroos in 2018 (1,133,523) was relatively unchanged in 2019 (1,124,115). And the neighbouring South Australian zone (Eastern Districts) experienced, from 2018 to 2019, only a 15.4% drop in its red kangaroo population, from 63,947 to 54,091. If every one of these South Australians had migrated to New South

Wales, rather than dying as I think it was assumed they had, it's hard to see how they could have increased the Lower Darling population more than a fraction of the figure given. So no, not migration, at least not enough to explain the leap.

One might have thought, alternatively, the problem might be that the 2019 Lower Darling survey sample had been selected from a part of the zone where for one reason or another there'd been, at the time, a much higher concentration of roos than in the rest of the zone and that, extrapolated *to* the rest of the zone, this had produced a greatly inflated figure. The designers of the surveys, however, seem to have foreseen such possibilities and limited them (if not obviated them) by spacing, more or less evenly across a zone, the transects an aircraft must fly, so that the sample, small as it might be, nevertheless comprises a number of even smaller samples taken from across the whole. Miniscule as the overall sample sizes remain, this, with limited resources, would seem the best that can be done, and certainly better than situating the transects contiguously (i.e. side-by-side).[20] Even allowing for a 20% margin of error (as seems to be the case), it's hard to see how such a method, and (as we have seen) the limited number of kangaroos actually detected, would lead to such massive leaps in population as are in question. With this ruled out, however, where else to look?

Might the problem lie, not in the raw survey data itself, but in the method with which that data is processed?

It would seem at the very least that, for all the factors already being taken into consideration in that processing (to do with roos *un*seen, to do with variations in terrain, etc.), a significant limiting factor may have been being overlooked (let's call it Factor X), and – not to impute malintent – may even, up until this point, have been unknown. But about this, of course, and while there have been some very pertinent suggestions – that frequent changes in survey and data-processing methodologies have rendered year-by-year estimates essentially in-comparable; that changes to (*elevations* of) correction factors amount to consistent systemic inflation; that failure to provide *control* samples (additional replicates) means that raw data cannot be verified or aberrations caught, etc.[21] – I'm not sure there is very much that at this point can be said without considerably extending this paper.

What *can* be said is that these dramatic, biologically impossible leaps, where they occur, do not appear to set off alarm bells for those who produce or are working with them – at least, not enough to prompt comment, let alone explanation, in their reports.

How might this have come about?

## A Backstory

Whether to exploit them as product, or to reduce their impact on other industries (beef, wool, lamb, mutton), the mass killing of kangaroos for commercial reasons has a long history, much of it based on the assumption that kangaroos are plentiful – a pest on the one hand, an inexhaustible resource on the other – and in the absence of any real accompanying attempts to gauge population size. I have presented some of this history elsewhere, and am far from alone in doing so.[22] For the present discussion, I need go back only as far as January 1973 when, supposedly in response to pressure from conservationists and concerned members of the public, the Australian Minister for Customs and Excise (Lionel Murphy) withdrew his consent to the export of kangaroo products and suspended the trade until he could be 'assured that kangaroo killing would not endanger the species'.[23] A report was subsequently prepared, the Australian Minister for Environment and Conservation was promised annual population figures and quotas from participating states, and, the Minister for Customs and Excise satisfied, the export – and the killing – resumed.

Tempting as it might be to see this as a piece of independent Australian common sense, there were other factors involved. The United States was at this point the largest market for kangaroo products (and is still very nearly so). Congress had passed the Endangered Species Act in 1973. Early in 1974 the Fish and Wildlife Service of the US Department of the Interior had banned the importation of products derived from red and grey kangaroos, concerned that supplying the US market would threaten those species' survival, and had placed both on its endangered list, a huge blow for Australian suppliers.

The first official quotas and population estimates, in other words, were produced in order to re-open a market and demonstrate that enough kangaroos could be shot to supply it without compromising the survival of the species. At this point aerial surveys were in their infancy, ground surveys very limited, and uncertainties greatly outweighed the certainties, a paucity of contemporary knowledge reflected in the array of estimates produced at this time and in the years immediately following. In 1980 an officer of the US Fish and Wildlife Service, visiting Australia, came up with a figure of 32,650,000 for the three main species. In 1983 the Australian National Parks and Wildlife Service sent a figure of 18,135,600 for 48% of the Australian landmass – a figure which, disregarding advice that the other 52% was thin on kangaroos, the US agencies then doubled. In the same year an Australian Information Service fact sheet, published by the Australian Embassy in Washington, gave a figure of 21 million eastern and western grey kangaroos and red kangaroos, but suggested there could be as many as 60 million. Later that year the University of Sydney came up with a total of 19.1 million kangaroos for the whole of Australia.[24]

Such figures, it seems, were based less on fact than on beliefs and assumptions about kangaroos on the one hand, and on industry aspirations on the other. It would seem too that, if you base a system upon beliefs, assumptions and aspirations – build that system *around* them (and feed into it figures that are already inflated) – they can be very difficult to remove.

The national harvest quota system still performs the function of providing evidence of sustainability to its markets. And whether they are a product of the surveys themselves, or of the way the figures from these surveys are subsequently processed, the aspirational distortions which entered the system at its ground floor – which established that system's parameters – are arguably still there, embedded in that system's benchmarks and processes (that very optimistic 15%, for example, as a standard for yearly population growth), its terminology (population estimates and fluctuations, in the quota reports, are *trends in abundance*; a population on the verge of regional extinction is a population of 'low abundance', i.e. still abundant, just not as abundant as others), in the manner in which statistical data is selected (which factors are seen as necessary to take into account, and which seen as unnecessary), the way it is presented (all units, for example, are presented as equal, but are they? there is a long and unresolved debate

concerning the possible effects of harvesting upon the macropod gene pools, bolstered by a sense that 'the big roos' have gone, and that the 'average' roo of today is not what he/she was just thirty years ago[25]), and the ways it is applied and adapted.

What might these beliefs and assumptions be?

## Beliefs and Assumptions

That kangaroos are a pest, for example. That they are 'in plague proportions'. That they are a danger to the pastoral industry. That for every kangaroo on one's property one could be feeding two sheep. That they must be managed and controlled. That we have a right, therefore, even a duty, to kill them. And new versions continue to appear: that their overgrazing is killing our native forests; that it endangers our biodiversity. Almost all of them, more to the point, overlap or are contingent upon beliefs concerning their ability to recover from or withstand, as a species, the damage we wreak upon them. The belief that they are abundant. The belief that they are a 'boom and bust' species. That their populations can 'explode'. That kangaroo females can have three joeys at the same time (after all, they have three vaginas, don't they?). All of them essentially faces of the same core belief, better call it a myth, of their hyperfecundity.

It would appear to be widely assumed that, because a kangaroo doe is reputedly *capable*, biologically, of having three young at the same time – an at-foot (out-of-pouch) joey, a pouch joey, and an embryo-in-waiting (through a phenomenon known as *embryonic diapause*[26]) – this, in a good season, will in fact be the norm: an assumption, as it were, of maximum fecundity. This is at once a furphy, a category error, and a gross exaggeration. In the second most populous of the species in question, the eastern grey kangaroo, the occurrence of embryonic diapause (for example) is 'uncommon'.[27] In the third most populous, the western grey, it does not occur at all. Leaving aside the question as to whether we can speak of an embryo-in-waiting – a blastocyst – as a third young in the first place, an *alternative* view of the same phenomenon, in the minority of female kangaroos for whom it is any kind of factor at all (we are speaking mainly of the red kangaroo) is that this capacity is an indication not of extreme *fecundity*, but of the great difficulty of seeing joeys past infancy, and the way evolution has tried to deal with this difficulty.

Representatives of the kangaroo industry, and representatives of the government representing those representatives, have nevertheless suggested, and keep suggesting, that a kangaroo doe can, accordingly, 'have' three joeys in a year.

It may seem a small point upon which to focus, but I would argue it is more important to understand this particular point – to *get this point right* – than it is to understand almost anything else about kangaroos. In some senses it's upon this particular point that their fate depends. *If* a kangaroo doe *can* have three joeys in a 'good', which is largely to say *non-drought* year, then the kangaroo population could very well be presumed to be able to recover quite quickly from a string of not-so-good years. A mob of 30 with a female-to-male ratio of two-to-one, for example (not so unusual a ratio nowadays, when, after considerable overseas concern at the manner in which joeys are dispensed in the field, shooters are encouraged by the kangaroo industry to shoot only male kangaroos), could conceivably, within a twelve-month period, become a mob of 90, a 200% increase. And of course, *if* that were the case, we could, yes, speak of kangaroos – as just in the last few months[28] we've heard the Australian Minister for Agriculture, members of the NSW Kangaroo Management Task Force, representatives of the Kangaroo Industry of Australia, and various ecologists and conservationists who *should know better* speak of them – as a 'boom and bust' species.

The problem, of course, is that this is *not* the case. Kangaroos, yes, are a 'bust' species – drought sees to that – but they do not 'boom': their populations do not 'explode'. Increases of 200% are biologically impossible. Increases of *20%* are close to impossible. A kangaroo doe can 'have' three joeys in a year only in the sense that, throughout my childhood, the woman who lived next door to us 'had' three children every year of my childhood. She had Andrew, the eldest, Penny, four years younger, and Graham, two years younger still. But did she *produce* – give birth to – all three in one year, and repeat that miraculous feat every year? Hardly. And a kangaroo doe can't either. To suggest otherwise is total misrepresentation of the biology: or, to put it more bluntly, balderdash.

The actual reproductive capacity of a kangaroo doe is very different, and I will come to it very shortly. There are some other things it will help to consider beforehand.

That *proportion of males to females* in the kangaroo population, for example, and the *survival rate* of newborn and infant kangaroos. The higher the proportion of females to males in the kangaroo population overall, the higher the number of joeys one might plausibly expect, and the higher the survival rate one factors into one's equation, the more joeys will be projected to make it into the next year. In any year, too, a certain number of the adult kangaroos in any mob will die of natural or unnatural causes, and this attrition must be allowed for in any calculation of a kangaroo population's ability to increase, or recover from the damage drought or human incursion have done to it.

One must also allow that a certain proportion of females in any mob will be either too young or too old to reproduce. Eastern grey females reach sexual maturity at around 18 months, western greys at around 14, red kangaroos between 15 and 20 months, and wallaroo/euros between 18 and 24 months. But we should be careful with that word 'maturity': they can get *pregnant* at these ages, and can give birth a while later, but kangaroos *learn* to be mothers. Their capacity to raise their first infants to adulthood is limited. A joey's chances of survival as a first- or second-born are poor.

The death rate amongst the adult kangaroo population in an unexceptional year[29] seems fairly undisputed at 5%, but there's little consensus on any of the rest of these figures.[30] The male-to-female ratio, for example, varies from parity (one-to-one) to a 1:2 ratio, i.e. twice as many females as there are males; the pre-adult survival rate varies from an approximate 25% up to around 50% (i.e. a mortality rate of 75% and 50% respectively). Although some have estimated the proportion of 'unproductive' females in a mob is as high as 36%, one suspects that the figure factored into the government's forward estimates is far lower (between 5 and 10%), if it's factored in at all.

## The Limits of the Possible and the Myth of Hyperfecundity

I've drawn up a set of calculations in order to demonstrate, amongst other things, the effect a shift in one or another of the factors abovementioned can have on an overall percentage (/rate) at which a kangaroo population can be expected to grow or recover. Annual kangaroo population growth rates estimated by various experts, bureaucrats and industry representatives range from as low as 9% (observation of the regrowth rate of the Wandoo Woodland western grey population[31]) to as high as 67% and 92% (Pople and Griggs, 1999, concerning the reproduction rate of red kangaroos).[32] One other thing I hope these calculations demonstrate – my principal objective – is that some of the rates put forward *as fact* in annual government estimations are, at least biologically, impossible.

Each calculation presumes a base mob size of one hundred kangaroos. Here is a cautiously optimistic version:

100 kangaroos

50% female (i.e., a ratio of 1:1)

→50 does

minus a proportion of those (20%) either too young or too old to reproduce

→ 40 does (80% of females) producing *1.5 young per year* (that is, three young over a two-year period: close to the biological upper limit)

→ 60 young per year total

with a 25% survival rate (i.e., one out of four reaching adulthood)

→ 15 additions to the population (now 115 kangaroos)

Subtract adult mortality of 5% of the original 100 (i.e., 5 individuals)

→ adjusted population figure of *110*

Subtract percentage 'harvested' (c.4% [=4 kangaroos])

→ adjusted additional number of *6* (i.e., **106 kangaroos at year's end**)

→ **6% population growth rate per year**

Pushing at the upper end of 'normal' as the proportions in this calculation do, some would nevertheless still assert that these figures are too conservative, so let me present some variations. If we change the proportion of female-to-male to 55/45, for example, reduce the proportion of those females too old or too young to reproduce from 20% to 5%, and (against biology) raise the number of joeys per year from 1.5 to (an impossible) 2.00, the absolute maximum growth rate figure climbs to **17%**, and if we maintain these adjustments but then raise the survival-rate figure from 25% to 50%, the absolute maximum growth rate figure becomes **43%**.

I would suggest, however, that we are already well into the territory of the implausible. And here we get to the grist of it. The myth of hyperfecundity. No 'expert' I've found lists an in-pouch period of less than 185 days, for *any* of the macropod species currently harvested. If a doe gives birth to a new infant *on the very day* that she shifts her previous joey permanently from the pouch, and if each of these joeys stays in the pouch for the 185-day lower-end estimate, then we are still looking at a 370-day period for the two, and the simple impossibility of a doe's raising two joeys from birth to leaving the pouch within a twelve month period. While I admit that, depending upon how early or late in the first year our calculations begin, it may be possible that two joeys will reach leaving-the-pouch 'maturity' within a calendar year (since the first of them began their development at some point in the year before), even this will not be possible, let alone likely, year after year.

It might nevertheless still be argued that two joeys a year is biologically just possible (it is *so* close: it would only be a *white* lie…), but how likely is it? It tends to assume, first of all, that the doe's body is operating like clockwork. René Descartes might have found this feasible, but there are other significant factors to consider. Some experts, I note, give the 185 as the lower end of a range extending *as high as 300* days, i.e., suggesting an in-pouch period of anywhere between six and ten months. This accords with figures from various wildlife sanctuaries and refuges suggesting an in-pouch period between 9 and 11 months.

In a scientific world that has at last begun to acknowledge sentience in higher-order mammals (and a great many other creatures), moreover, we can perhaps assert, too, that the emotions and judgement of the doe (*and* the joey) might have some role here. A doe who lost

her previous pouch- or at-foot joey to a fox or eagle or dingo, let's say, might (*learning to mother*) wish to keep the next joey in the pouch a little longer. She might also make a judgement as to whether her joey is ready enough – *mature* enough – to become an at-foot joey. Some may be ready at 185 days (does she count the days? not likely), but others may require two or three months more.

The only way, I would suggest, that, under such circumstances, a doe might *produce* two joeys in a year, from birth to leaving the pouch, is if there is some *overlap*,[33] i.e., if a second, immature joey can be in the pouch at the same time as a much larger and more mature joey who is not yet ready to be evicted. But this, while apparently not impossible – a newborn, bean-sized kangaroo can almost weld itself to the mother's teat – is biologically most unlikely. A doe tends not to give birth to another joey while there is a joey still in the pouch, indeed one of the functions of embryonic diapause is to ensure that this does not occur. The departure/eviction of a joey from the pouch stimulates, in the mother, an hormonal shift that signals another birth is possible. There is a simple evolutionary logic to this. A tiny, very fragile joey, weld itself to the teat as it might, is not going to thrive in a pouch which has a much larger joey scrambling into and out of it. So, overlap conceivable, yes, but highly unlikely. If we are going to make any high-end assumptions at all about kangaroo reproductivity, common sense suggests they should be in the vicinity of three joeys seen to at-foot status over a period of two years, or one-and-a-half joeys per year, and then only under optimal conditions.

There is, however, a further factor which might lead us to raise the overall annual population growth rate. Given that males tend to be the principal guardians of the mob, given that the males do actually fight (although rarely to the death) for their place in the reproduction hierarchy, and given, perhaps especially, that the kangaroo industry has for some years now favoured a male-only harvesting policy, it would appear there has been a gradual decline in the proportion of males in the population, and that in some areas the female-to-male ratio may now be more like two-to-one. It seems only appropriate, then, to present a revised form of my original calculation, with the ratio now 65% female to 35% male:

100 kangaroos

65% female

minus a proportion of those (20%) either too young or too old to reproduce (i.e., 13)

→ 52/100 (80% of females) producing 1.5 young per year (the biological upper limit?)

→ 78 young per year total

with 25% survival rate (to adulthood)

→ 19.5 (say 20) additions to the population.

Allow for adult mortality of 5%

→ adjusted addition number of *15*.

Subtract c.4% 'harvested' (4 kangaroos)

→adjusted additional number of *11*

→ **11% population growth rate per year**

Even here I imagine there will be those who feel I exaggerate the constraints, so let me adjust to their most optimistic extremities all factors in the equation, i.e., reduce to 10% those females either too young or too old to reproduce, raise the joey survival rate from 25% to 50%, and raise the number of new joeys per doe per year to a biologically stretched 1.75. The population growth rate will now be **42%** per year, an interesting figure to contemplate – and to offer to one's markets and governmental overseers (and, through the latter, to the public) – but, although others may not (annual increases of this proportion are extremely common in government tables), I fail to see how such a percentage could ever be possible.

If we follow the *myth*, however – set the number of joeys per year at a biologically absolutely impossible *three*, with the male-to-female ratio of one-to-two – the growth rate leaps dramatically:

100 kangaroos

65% female

Minus a proportion of those (10%) either too young or too old to reproduce (i.e., 6.5)

→ 58.5/100 (90% of females) producing 3 young per year (the biological upper limit?)

→ 176 new young per year

with *50% survival rate* (to adulthood)

→ 88 additions to the population

subtract adult mortality of 5%

→ adjusted addition number of *83*

subtract percentage 'harvested' (c.4%, =4 kangaroos)

→adjusted additional number of *179*

**→79% population growth rate per year**

We begin to see, I think, where a great many of the gross exaggerations in those tables might come from, and what might be sustaining them. How else explain that annual rises of this clearly impossible amount *or greater* appear, sometimes five or six times, in the thirty-year historical population figures for Tibooburra, Cobar, Broken Hill, Lower Darling and almost every other KMZ in New South Wales? When in truth even the 15% the government, with its other hand, appears to have set as a normative annual rise (i.e., as a proportion that may be culled without affecting the overall population) exceeds the 10-12% growth rate put forward by several independent kangaroo experts.

I can't pretend that such calculations do any more than begin to unpack the disconnect in the published kangaroo population estimates, but with luck the point is made. The safest option, for those truly concerned for kangaroo welfare, would be to ignore those estimates entirely. But of course, we cannot do that: *these myths, exaggerations and miscalculations are propelling an extinction*. Better to learn to read between and behind their lines: to see them for what I think they are, a set of smoke-and-mirror effects calculated to sustain the illusion of

abundance. It is hard to see how they could in any way approximate reality or perform any other function than to mask the true extent of the damage already done to the species and perpetuate the gross delinquency of the industry. The kangaroo may be a hair's breadth from extinction in twenty or thirty years' time but the money will have been made, the pockets lined.

## The Take

Perhaps the only official figures we *can* place some faith in are those, near the end of each quota report, for the number of individual kangaroos of each species shot and (gutted, their heads and feet severed) delivered to chiller boxes, registered, and processed each year by the industry. These figures – the *take* figures – are harder to manipulate, and tell quite another story.[34]

These figures peaked in the 1990s and for a decade from 1993 until 2002 the 'take' in NSW averaged over one million kangaroos a year, achieving an average of 75% of their yearly quota and 8.5% of the overall population. The last decade of available figures, however, is eloquent in its difference. For seven of the last ten years (2010-2019) the take has sat very steadily within twenty to twenty-five thousand of a mean of about 360,000 kangaroos. The only exceptional years, and they have not been hugely so, were 2018 and 2019, when the recent drought was biting and what I call the *drought paradox* came into play. (As the landscape becomes drier and forage reduces, kangaroos become more evident along roadsides and near settlements and remaining water sources, or gathered at exclusion fences, driven by thirst and hunger, congregating *not* because they are supernumerary – the dry plains are emptying behind them – but because they are desperate. That they are *seen* so much more during these periods not only creates the impression of 'plague' proportions, but also, of course, means they are easier to find and kill.)

The estimated NSW population, over this second ten-year period, has fluctuated widely (from a low of eight million to a high of seventeen), and the quotas have ranged from as high as 2.7 million to as low as one million, but the number of kangaroos actually registered as having been shot has dropped dramatically – halved – from that of two decades before. And stayed at this low level throughout, as if the 'take' has reached, somehow, a *limit of the possible*, regardless

of what the government has been led to predict, hope for, or determine permissible. The take as a percentage of the quota has dropped from an average of 75%, in 1992-2002, to an average of 21.6% in 2010-2019, and as a percentage of the overall 'population' has dropped from an average of 8.5 to an average of 3.2.

What creates – or rather limits – this possible is not entirely clear. It may be the shooters, but it may also be the shot. The kangaroo industry, pointing to the government figures, insists there are plenty of kangaroos to be shot, just not enough people to shoot them, but it's hard to imagine how it could be anything but a case of shooters (as they have been telling us) finding the quarry too scarce and meagre to make shooting them worthwhile. How, if kangaroos *are* as abundant as population estimates and the kangaroo industry suggest, could this be so? I may be almost alone in this interpretation but this – and the fact that the overall take dropped dramatically in the years 2006-2010 and has not really risen in the decade since – suggests to me we've reached a point that we must examine very closely, one of the clearest indications we have had yet that the species are declining, and that the kangaroo industry, as such, is no longer viable, if it ever was. The great tragedy is that kangaroos are still being slaughtered, at an unacceptable rate (as if there were such a thing as an acceptable one), in the attempt to prove otherwise.

Eloquent – and reliable – as I think these 'take' figures are, of course, they too carry their own deception. Shooters compelled by the kangaroo industry's male-only shooting policy report that, such are the conditions under which shooting takes place (at night, at telescopic-lens distance), as many as one in three kangaroos shot is nevertheless female. The industry does take some of these – one presumes only the largest – but most are left in the field. It's also estimated that at least two in three of females shot have joeys in the pouch, and that at as many of these females shot have an at-foot joey nearby when their killing occurs.

For every *take* figure, that's to say, there's also a *leave*. For every nine roos shot there is the likelihood only six will be taken, and that three females will be left in the field, along with two pouch joeys disposed of ('euthanised') in accordance with the recommended Code of Practice ('by a blunt trauma to the skull'), and one or two at-foot joeys who, their mothers

dead, will die through exposure or predation (it is not uncommon for shooters to be attended by a skulk of foxes, who clean up after them). For every six 'taken', then, there the possibility – the likelihood – that six others also die. And perhaps more. I've not added in a figure for animals shot but not killed outright, and whom, although obliged by the Code of Practice to follow up and euthanise, shooters have not been able to find in the dark (and who'll very likely die in agony). The take, in other words, is not the kill. The kill is nearly twice the size of the take.

Officials from the NSW Department of Planning, Industry and Environment currently responsible for the state's kangaroo harvest would likely disagree. I have just been reading one of them who claims that, on the one or two occasions when he has accompanied shooters into the field, they have been so well-trained, and so observant of the Code of Practice, that they have shot with 100% accuracy, not a bullet wasted. No 'ghost' figures, no collateral deaths, no *leave* to the take. Representatives of the DPIE have also claimed that widespread baiting for foxes and wild dogs has been so successful that predation upon young kangaroos had declined to a point where, in good years, a joey survival rate of just under 75% might be used as a benchmark. They have claimed, too, that the extraordinary increases in population littering their tables are due to the way droughts, in taking, on the one side, the largest and, on the other, the youngest of adult kangaroos, dramatically increase the ratio of productive females to males.[35]

While I'd accept that these factors, were we to find them in any way plausible, *could* lead, briefly, to some steep rises in population, they would still be subject to upper limits of the kind already built into my calculations. A mob with a female-to-male ratio of three to one, for example, and a 75% joey survival rate, would be pushed to exceed a 78.5% increase in an exceptional post-drought year. Even a mob with a ratio of *nine* females to each male could not exceed 97%. These figures, already far into the territory of the biologically impossible, are still a long way short of the growth rates well in excess of the 150% that the tables in quota reports so frequently claim.

Doubtless there will be many keenly awaiting the next release of state and national population estimates and accompanying 'harvest' quotas, however rubbery those figures are, whatever percentage is made up of kangaroos who may not be there and whose existence cannot

be proven, and whatever spin governments may place upon whatever other anomalies in those figures there might be. The kangaroo industry and others exploiting kangaroos commercially will hope those estimates are high, and those who advocate for kangaroos and seek to ensure their continued existence will face their usual heart-wrenching dilemma: to hope/not hope for a fall in numbers which may, in strengthening their argument, bring about some relief for kangaroos, but will also confirm their present suffering, or to hope/not hope for a rise in numbers which, although it may indicate some health in the population, will also invite greater attempts to reduce it.

But then it's those advocates, of all people, who should know that while numbers *must* concern them – while they're a treacherous game they've no choice but to follow – it's not, ultimately, about numbers. The ethics of numbers are confusing because, in this regard, there are no ethics in numbers at all. In the Empire of Numbers it can be hard to remember this. Whether there be one hundred million, or (God forbid) only one hundred thousand, every kangaroo life *is* a life, a being, intense with that being. We have no right whatsoever to bring it to an end.

## Notes

[1] A very conservative figure, for reasons later explained.

[2] 'Four years ago, there were nearly 5,000 professional roo shooters across Australia. Now there are fewer than 1,800, as tough conditions and a fluctuating market have pushed all but the most determined from the industry' (Alex Mann, 'Kangaroo Shooters on the Decline with Industry Set to Expand,' *ABC News*, 9 Jun. 2014, http://www.abc.net.au/news/2014-06-09/kangaroo-shooters-on-the-decline-with-industry-set-to-expand/5510812). 'Bruce Duncan from NSW Farmers Association said the restrictions on what shooters could and could not do made it difficult and there were fewer and fewer shooters in areas such as far-western NSW. "There used to be 12 shooters here. Now, there's one who does it as part-time after work," he said' (Kieu Trinh Nguyen and David Claughton, 'Kangaroo Management Fails Farmers in Record Roo Numbers', *ABC News*, 29 Sep. 2017, http://www.abc.net.au/news/rural/2017-09-29/kangaroo-management-fails-farmers-in-record-roo-numbers/8993148. 'The *number* of NSW commercial *kangaroo* harvesters has *declined* dramatically from seven years ago from approximately 900 to 380 last year' (John Ellicott, 'Little Pay Incentive For Shooters to Join Kangaroo Meat Industry,' *The Land*, 15 Mar. 2018, https://www.theland.com.au/story/5285265/top-roo-shooter-says-harvesting-is-a-low-paid-job/.

[3] *2021 Quota Report: New South Wales Commercial Kangaroo Harvest Management Plan 2017-2021*. Department of Planning, Industry and Environment (2020).

[4] Mjadwesch (2021) provides powerful statistical evidence of this decline.

[5] States shooting kangaroos for the domestic market have not so far had to register kangaroo management plans or population estimates.

[6] For an account of which see Brooks 2016 ('Roogate').

[7] Some small changes and adjustments – surveying in zigzags, surveying in blocks – have been made in the ensuing decade.

[8] See Mjadwesch (2011).

[9] 'All population surveys', I am assured, 'whether for wildlife or for people, take a sample and extrapolate'.

[10] See Parliament of New South Wales (2021), virtual hearing via videoconference, 19 August 2021, transcript, p.8.

[11] See R. Mjadwesch (2011 and 2021) for more detailed takes on survey methods and result processing.

[12] Glen Innes, Armidale, Upper Hunter, South-eastern NSW, Central Tablelands North, and Central Tablelands South.

[13] See for example Wilson (2021).

[14] At the beginning of the year, that is to say, a 15% quota set on the basis of the previous year's figure (405,079) would, if the population had begun to decline, already be three months out of date, and the 60,762 quota already represent somewhat more than 15% of the targeted population, and as the population continued to decline (aided partly by the mounting number of kangaroos harvested) this percentage would keep growing. If, as the next survey (September 2017) indicates, the population had dropped to 184,069, the 60,762 quota, *with three months still to run*, would be representing approximately 33% of the target population.

[15] Not that we can leave this troublesome 2019 Cobar eastern grey kangaroo figure here. The survey was conducted in late 2019, just before the megafires of late 2019/early 2020. A severe drought was at its peak. If anything, one would have expected eastern grey numbers to have been even lower than in those produced by the 2018 survey. This anomaly remains unexplained in published reports. Even were it possible to authenticate the 44,208 figure, the density of 1.1 kangaroos per $km^2$ is lower than the government's own cut-off point (1.2 kangaroos per $km^2$) for any shooting. By the government's own regulation, no quota should have been requested for 2021.

[16] Parliament of New South Wales (2021), virtual hearing via videoconference, Thursday 19 August 2021, transcript, p.6.

[17] On this point the Kangaroos at Risk website cites D. Priddell, N. Sheppard, and M. Ellis, 'Homing by the Red Kangaroo Macropus rufus', *Australian Mammalogy* vol. 11, 1988, pp. 171-172, and M.J.S. Denny, 'Red Kangaroo Arid Zone Studies', an unpublished report to Australian National Parks & Wildlife Service, Canberra (1980). See https://www.kangaroosatrisk.net/2-biology--population-ecology.html

[18] Where **N**=estimate of overall population; **M**=the number initially captured and marked; **C**=total number in the second captured group; **R**=the number of marked individuals in the second group.

[19] It's hard to think that experienced population surveyors and statisticians would not know this, or that the use of MRDS in situations where migration is a factor is likely to lead to over-estimations of population. Might it have been introduced for this very purpose?

[20] If I have not made this sufficiently clear, a visit to Cairns et al (2020) might resolve the issue.

[21] See Mjadwesch (2011).

[22] For an account of the 'wild shooting' of kangaroos since European settlement see Gelder & Weaver, 2020, or Brooks, 2018.

[23] See Parliament of the Commonwealth of Australia (1988), 59.

[24] *Ibid* 60-62.

[25] 'Minimum carcass weight', for example, has been repeatedly lowered by the industry itself, in order to ensure supply (see Pople et al, 2006: 294). Scientists have repeatedly warned that continued harvesting will affect the gene pool of targeted species (for example, Croft 2000, Pople 1996, O'Brien 2004).

[26] A phenomenon whereby a fertilised ovum/blastocyst is kept as a 'spare' to be released upon an hormonal signal, indicating that adverse seasonal conditions have improved, for example (and

nutrition increased), or that a pouch joey has reached the at-foot stage, i.e., leaving the pouch free.

[27] Terrence J. Dawson (2012), 66.

[28] I write this in late 2021, early 2022.

[29] That is, with no mass deaths from drought, disease, etc.

[30] I have based my estimations of the range of these and the other variables in the tables which follow on an accompanying range of general and specialist texts, for example Jackson and Vernes, Simons, Staker, Dawson, Pople (2006) and the Kangaroos at Risk website.

[31] See Arnold et al. (1991), 561-75.

[32] If there is any consensus at all concerning kangaroo population annual growth rates, it would seem to hover around 10%. The Kangaroos at Risk website suggests 'an Eastern Grey Kangaroo population growth rate of 10%, a Red Kangaroo population growth rate of 13.5%, a Wallaroo population growth rate of 14%, and a Euro population growth rate of 12%' http://www.kangaroosatrisk.net/2-biology--population-ecology.html (21.iv.18). See also Daniel Ramp and Karl Vernes: 'Juvenile mortality rates are high and female kangaroos tend to have only three or four joeys survive in their lifetime. Compare that to rabbits, which can produce up to 14 young in a litter. Kangaroo populations, as a whole, do not grow more than 10% in a year' ('Fact Check: Are Kangaroos at Risk? *The Conversation* https://theconversation.com/factcheck-are-kangaroos-at-risk-37757 (21.iv.18)).

[33] Kangaroo twins are very rare. They have been known to occur, but there is no record of both surviving.

[34] A point made by Mjadwesch a decade ago (2011).

[35] See Parliament of New South Wales (2021), virtual hearing via videoconference, Thursday 19 August, transcript, pages 15 and 5 respectively.

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