# Kangaroo harvest quotas for Victoria, 2021

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**Acknowledgment**

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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**Front cover photo**: Western Grey Kangaroo and Joey (Source: Getty Images).



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# Kangaroo harvest quotas for Victoria, 2021

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# Summary


## Context:

The Victorian Government has adopted a policy of supporting ecologically sustainable commercial harvesting of wild Grey Kangaroo (Eastern Grey Kangaroo, *Macropus giganteus* and Western Grey Kangaroo, *M. fuliginosus*) populations in the state. To support the implementation of this policy, there is a requirement to set ecologically sustainable harvesting quotas to avoid overexploitation of kangaroo populations.

## Aims:

Using the kangaroo abundance estimates derived from the statewide aerial survey conducted in October 2020, recommend a maximum sustainable offtake of Eastern and Western Grey Kangaroos and apportion the total offtake among the demands from the ATCW permit process and the kangaroo commercial harvest program (KHP).

## Methods:

The annual total sustainable quota for 2021 was assessed as being no more than 10% of the abundance of each species of grey kangaroo. The predicted demand for kangaroos authorised through the ATCW permit process in 2021 was estimated by analysing the historical ATCW kangaroo numbers using several time-series models. The model with the best (training) predictive accuracy was then used to predict the likely demand for kangaroo control through ATCW permits in 2021. The total sustainable quota was then apportioned between the expected demands for both ATCW permits and the KHP.

## Results:

The total sustainable quota for 2021 was assessed as being 191,200 kangaroos comprising 176,650 Eastern Grey Kangaroos, and 14,550 Western Grey Kangaroos. Predicted demand for kangaroos under the ATCW permit process was estimated to comprise approximately 62% of the total quota for 2021 comprising 119,400 grey kangaroos. However, demand in the Mallee and North East harvest management zones was predicted to exceed the recommended sustainable level of take for those zones. This left an allocation of 71,800 kangaroos for the KHP, after adjusting for the total predicted ATCW demand.

## Conclusions and implications:

Kangaroo abundance in 2020 has increased by approximately 41% (95% CI; 22% to 60%) for Eastern Grey Kangaroo and 12% (95% CI; –3% to 27%) for Western Grey Kangaroo across the state, compared with the 2018 aerial survey. However, populations in both the Mallee and North East zones have declined, coinciding with a recent increased demand for kangaroo control through ATCW permits in these zones. The level of offtake in these zones has been greater than the 10% currently recommended as sustainable, and hence the kangaroo populations in these zones may be at some risk of overharvest if this level of offtake continues. Consequently, no KHP quota has been recommended for the Mallee or the North East zone.

## Recommendations:

- For the 2021 calendar year, a total of 191,200 Grey Kangaroos is recommended as the maximum sustainable offtake. This includes kangaroos taken in the commercial harvest program (KHP) and through ATCW permits. The sustainable kangaroo offtake in each harvest management zone, apportioned between the KHP and ATCW permit process, is shown in Table 7.
- It would be desirable for the majority of kangaroos that would otherwise by authorised through ATCW permits to be commercially harvested through the KHP, as this would enable more accurate tracking of the total take of kangaroos. In addition, increased use of the KHP should lead to less wastage of carcases, improved animal welfare outcomes, and economic benefits for the state's commercial kangaroo harvesters.
- If a proportion of the kangaroo control predicted to occur under the ATCW system could, instead, be carried out by commercial harvesters under the KHP, the KHP quota could be adjusted accordingly, while still maintaining a sustainable level of take across the state. An alternative recommended quota accounting for a proportionate transfer from ATCW to KHP of 20% is outlined in Table 8.
- If a proportion of predicted ATCW control is not transferred to the KHP in the Mallee harvest management zone, no commercial harvest is recommended in this zone during 2021 to protect Western

Grey Kangaroo populations in the region from potential overharvesting. Reducing harvest rates for Western Grey Kangaroos in the Upper and Lower Wimmera zones will not compensate for overharvesting in the Mallee zone, but it will mitigate the risks on the Western Grey Kangaroo population as a whole.

- If a proportion of predicted ATCW control is not transferred to the KHP in the North East zone, no commercial harvest is recommended in this zone for 2021 to protect Eastern Grey Kangaroos in the region from potential overharvesting. Reducing harvest rates on Eastern Grey Kangaroos in the adjacent Central zone will not compensate for overharvest in the North East zone but will mitigate the risks on the Eastern Grey Kangaroo population as a whole.
- Kangaroos authorised to be taken through the ATCW permit process should be carefully monitored in both the Mallee and North East harvest zones to ensure demand does not exceed the maximum recommended sustainable offtake.
- Accurate and detailed harvest records, including the location, species, sex, and age class of all harvested kangaroos should be maintained. This is especially important for the Upper and Lower Wimmera harvest zones, so that the numbers of harvested Western and Eastern Grey Kangaroos from those harvest zones can be accurately assessed.

# 1 Introduction

Victoria's commercial kangaroo harvesting program (KHP) commenced on 1 October 2019, underpinned by the regulatory guidelines detailed in the *Victorian Kangaroo Harvest Management Plan* (DELWP 2020). The program enables authorised harvesters to take kangaroos for commercial purposes in designated areas of Victoria. The commercial take is limited by quotas, set across seven commercial harvesting zones, which are based on ecologically sustainable criteria (Scroggie and Ramsey 2019). The total allowable offtake of kangaroos in each harvest zone includes that taken by the KHP (KHP quota) and any kangaroos taken under the Authority to Control Wildlife (ATCW) provisions of the *Wildlife Act 1975* (Victoria). Under the ATCW provisions, kangaroos can be legally culled by landholders after being issued a permit by DELWP. To ensure the sustainability of the program, it is essential that the maximum number of kangaroos that are permitted to be taken under the KHP and ATCW quotas each year is determined on clear ecological criteria, with administrative and regulatory controls in place to ensure that populations are not overexploited.

Scroggie and Ramsey (2019) developed quotas based on a policy of allowing a maximum harvest fraction of 10% of the estimated kangaroo population in each calendar year. Proportional harvest quotas of 10% were recommended for the two kangaroo species that can be harvested in Victoria: Eastern Grey Kangaroo (*Macropus giganteus*) and Western Grey Kangaroo (*M. fuliginosus*).

The total quota is divided between seven harvest management zones, based on the proportion of the total state population in each zone. Because the quota for each harvest zone includes both the KHP and ATCW quotas, the regulatory framework needs to include mechanisms for apportioning the total ecologically sustainable harvest between these two categories.

The 10% quota recommended by Scroggie and Ramsey (2019) is conservative; quotas in other states are typically set at 15% (Hacker *et al.* 2004; McLeod *et al.* 2004). However, the 10% quota reflects the depauperate data on kangaroo population dynamics from Victoria in comparison with other states. Most available data and analyses pertinent to setting kangaroo harvest quotas have been collected from populations of Red Kangaroos (*Osphranter rufus*), Western Grey Kangaroos and Euros (*Macropus robustus*) inhabiting arid and semi-arid ecosystems, including rangeland ecosystems in New South Wales, Queensland and South Australia, from which long time-series of population monitoring data are available (i.e. more than 10 years). These long-term data have been used to construct stochastic population models for assessing the ecological risks associated with harvesting policies for arid-zone kangaroo populations (e.g. Caughley *et al.* 1987). Such models combine time-series observations of abundance or density of kangaroos with harvest statistics and data on presumed drivers of kangaroo demography (such as rainfall and pasture availability) to infer relationships between the rate at which kangaroo populations increase and spatially and temporally varying factors such as density dependence, resource availability and harvest offtake.

A similar model for examining the effect of spatially varying harvest has been developed for Grey Kangaroos in Victoria (Scroggie and Ramsey 2020). However, this model relied on ecological and demographic information collected from kangaroo populations elsewhere, because of a lack of comparable time-series abundance data for kangaroo populations in Victoria. As harvest and abundance monitoring data from Victoria accumulate, the spatial harvest model can be more reliably calibrated to represent the population dynamics of Victorian kangaroos, which should lead to greater confidence when using the model for management decisions, such as setting quotas. In the meantime, conservative quotas should be retained until adequate local monitoring data and management experience can be used to inform and validate the spatial harvest model for Victorian kangaroo populations.

This report presents an analysis to guide the setting of quotas for both the commercial harvest of kangaroos and those taken under ATCW permits in Victoria for the 2021 calendar year. This analysis is based primarily on the most recent monitoring data from the statewide aerial survey of kangaroos. We also used historical ATCW permit information to predict the likely demand for kangaroo permit numbers in 2021 and apportion the ATCW and commercial quotas for each harvest zone. In addition, we use the spatial harvest model to examine the extent to which various levels of harvesting in excess of the nominal 10% quota in a zone (up to 20%) could be offset by reducing quotas in neighbouring harvest zones.

# 2 Methods

## 2.1 Kangaroo abundance estimates

Moloney *et al*. (2017; 2018) used aerial survey data collected from the non-forested parts of Victoria (but including mallee vegetation types) to determine abundances of Red, Western Grey and Eastern Grey Kangaroos across the entire state. Full details of the survey methodology and interpretation are given in Moloney *et al*. (2017), Scroggie *et al*. (2017) and Moloney *et al*. (2018). The three kangaroo species are referred to hereafter as RK, EGK and WG; GK refers to both grey kangaroos combined.

The aerial surveys were designed around seven harvest management zones, with transects allocated randomly within the zones in proportion to their areas. The boundaries of the zones were formed by amalgamating adjacent local government areas (LGAs) with similar ecological features, land use and climate (Figure 1, Table 1). Separate estimates of abundance for RKs and GKs were derived from the aerial surveys. In the west of the state, the geographic ranges of EGKs and WGKs overlap substantially (Caughley *et al.* 1984), and as the two species cannot be reliably distinguished from the air, the aerial surveys alone did not allow apportionment of the total grey kangaroo population between the two species. To resolve this uncertainty, vehicle transect surveys were conducted across the overlap zone to estimate the spatial variation in the proportions of EGKs and WGKs, allowing the total count of GKs within each of these strata to be divided between the two species (Moloney *et al*. 2018). Collectively, the results of these surveys are the most up-to-date and comprehensive information on the status of kangaroo populations in Victoria and provide a robust basis for determining ecologically sustainable harvest quotas.

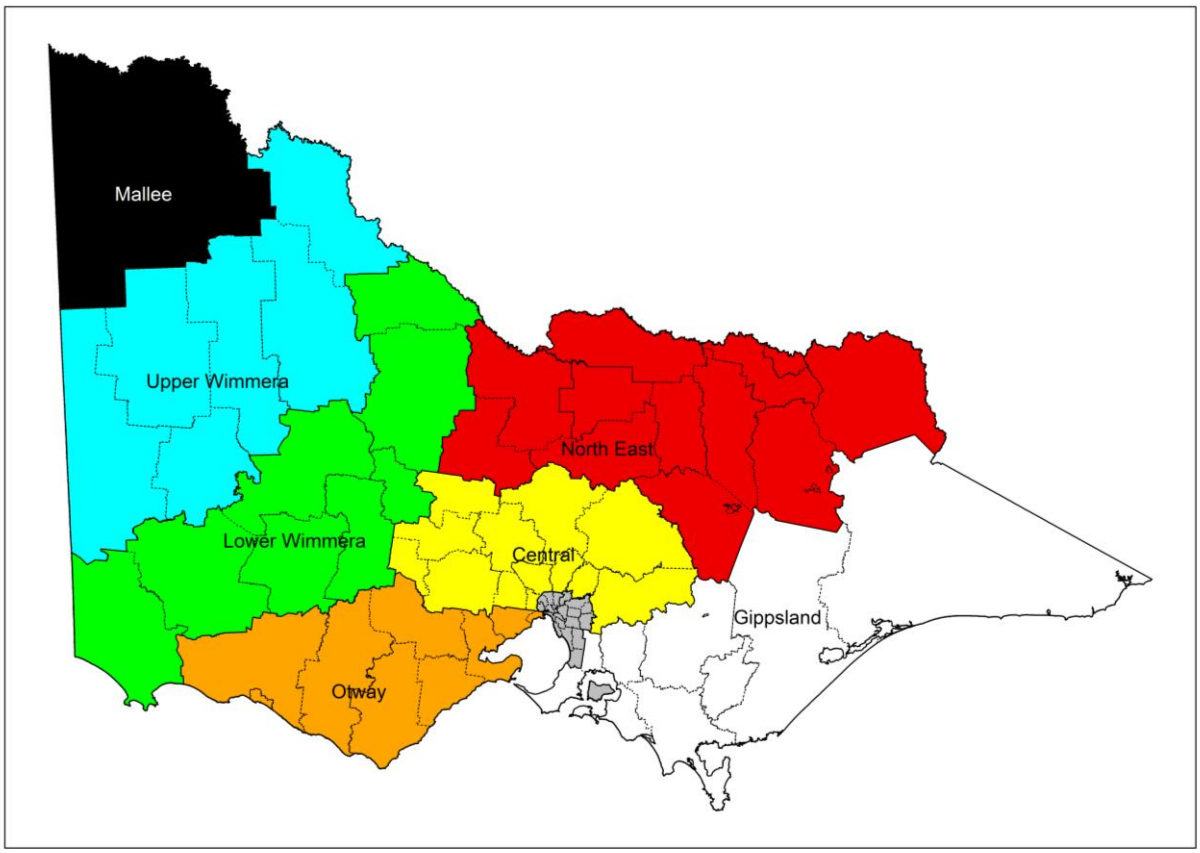


**Figure 1. Kangaroo harvest management zones in Victoria. Each zone is formed by amalgamating groups of ecologically similar local government areas. The grey shaded areas are not subject to harvest. Colour-coding of harvest management areas matches the colours of the tags attached to carcasses during commercial harvesting operations.**

**Table 1. Local Government Areas in each kangaroo aerial survey stratum (harvest zone) in Victoria.**

| Zone | LGAs | Zone | LGAs |
|---|---|---|---|
| **Mallee** | Mildura | **Central** | Ballarat |
| **Upper Wimmera** | Buloke | | Brimbank |
| | Hindmarsh | | Hepburn |
| | Horsham | | Hume |
| | Swan Hill | | Macedon Ranges |
| | West Wimmera | | Melton |
| | Yarriambiack | | Mitchell |
| **Lower Wimmera** | Ararat | | Moorabool |
| | Central Goldfields | | Mount Alexander |
| | Gannawarra | | Murrindindi |
| | Glenelg | | Nillumbik |
| | Loddon | | Whittlesea |
| | Northern Grampians | | Yarra Ranges |
| | Pyrenees | **North East** | Alpine |
| | Southern Grampians | | Benalla |
| **Otway** | Colac Otway | | Campaspe |
| | Corangamite | | Greater Bendigo |
| | Golden Plains | | Greater Shepparton |
| | Greater Geelong | | Indigo |
| | Hobsons Bay | | Mansfield |
| | Moyne | | Moira |
| | Surf Coast | | Strathbogie |
| | Warrnambool | | Towong |
| | Wyndham | | Wangaratta |
| **Gippsland** | Bass Coast | | Wodonga |
| | Baw Baw | | |
| | Cardinia | | |
| | Casey | | |
| | East Gippsland | | |
| | Latrobe | | |
| | Mornington Peninsula | | |
| | South Gippsland | | |
| | Wellington | | |

Aerial surveys of kangaroos within the seven harvest management zones were undertaken during October 2020 along 150 transects, comprising around 3000 km of survey effort. The abundances of EGKs and WGKs within each harvest zone were estimated using line transect methods and design-based inference; see Moloney *et al*. (2018) for details of the overall method.

## 2.2 Predicting demand for Kangaroos taken under ATCW permits

To achieve ecologically sustainable kangaroo management, the total number of kangaroos being culled must be managed, including not only the intended commercial harvest but also any other permitted culling under ATCW provisions. Because it is not possible to know, at the outset of a harvest period, how many ATCW applications will be received, the potential demand for ATCW permits is predicted by analysing the historical time series of kangaroo numbers authorised for control under ATCW permits.

Historical numbers of kangaroos authorised for control under ATCW permit provisions (hereafter ATCW numbers) were available for each harvest zone from 2002 to 2019. Although data from 2020 were available up to 30 October, these were not used for prediction because they are currently incomplete for the entire calendar year.

We modelled the historical time series of ATCW numbers for each zone using an exponential smoothing state-space model ETS (Holt 2004) as well as an autoregressive integrated moving average (ARIMA) model (Hyndman and Athanasopoulos 2019). Both models attempt to find trends in the time series for the purpose of forecasting (predicting) into the future. Exponential smoothing models weight observations, with weights decaying exponentially with time. Hence the ETS models place greater weight on more recent observations. ARIMA models employ both autoregressive and moving average components for smoothing and prediction. We fitted both ETS and ARIMA models to the time series of ATCW numbers and examined their relative predictive accuracy by examining the mean absolute scaled error (MASE) of the fitted models (Hyndman and Athanasopoulos 2019). The best model for each zone was then used to predict the likely number of kangaroos authorised under ATCW permits for the 2021 calendar year.

## 2.3 Sustainability of variable harvest rates among zones

One possible means of mitigating the impacts of undesirably high rates of harvesting in some of the kangaroo harvest management zones would be to reduce the rate of harvesting in adjacent zones. Under such a regime, the overall rate of harvesting would not exceed the recommended sustainable rate when considered over the whole state, although the rate(s) could still be higher than the recommended 10% in the few zones where over-harvesting was occurring. We explored the implications of such compensatory harvesting regimes using a modified version of the existing stochastic spatial harvest model for Victorian GK populations (Scroggie and Ramsey, 2020).

The most important innovation in the model used here, compared to the model described by Scroggie and Ramsey (2020), is that EGKs and WGKs are accounted for separately by placing each species in its own sub-model. This was considered essential for the current analysis, primarily because compensatory under-harvesting to offset over-harvesting elsewhere must logically be applied to the same species of kangaroo. For example, if WGKs are over-harvested in the Mallee harvest zone, then a compensatory harvest scheme can only be considered justifiable in those zones where WGKs occur, which in Victoria limits compensatory under-harvesting of WGKs to the Upper and Lower Wimmera harvest zones.

A similar argument applies to the situation with over-harvesting in the North East harvest management zone, which is occupied exclusively by EGKs. Compensatory under-harvesting to offset this over-harvest could only be considered justifiable if it was implemented in other harvest zones containing significant proportions of EGKs.

An additional consideration is that part of the likely mechanism by which compensatory under-harvest can offset localised over-harvest is by the dispersal of kangaroos into a harvest management zone where over-harvesting has occurred. For this reason, we only considered scenarios in which the compensatory under-harvesting was conducted in zones adjacent to those being over-harvested. For WGKs in the Mallee, these were the Upper and Lower Wimmera harvest management zones, and for EGKs in the North East, the compensatory under-harvest was applied to the Central harvest management zone. As dispersal of kangaroos over the Great Dividing Range from the Gippsland harvest management zone was considered implausible, the Gippsland zone was excluded from consideration in the model of EGK populations considered here.

Models representing some representative harvest regimes were run in order to estimate and compare resulting effects on ecological risks (Table 2). For all scenarios, GK populations in adjacent New South Wales and South Australia were harvested at a fixed rate of 15%. A baseline scenario for Victoria involved

harvesting at 10% in all zones. Two over-harvest scenarios were considered, with harvesting at rates of 15 or 20% in a single zone (Mallee or North East) without compensatory reductions elsewhere, while two compensatory scenarios considered reductions in harvest rate in zones adjacent to the over-harvested zones (Upper and Lower Wimmera, Central) to 5% (Table 2).

**Table 2. Simulated harvest scenarios examined using the spatial harvest model. The over-harvest zone is Mallee for Western Grey Kangaroos, and North East for Eastern Grey Kangaroos. The compensatory zones for Western Greys are Upper and Lower Wimmera, and Central for Eastern Greys.**

| Scenario | Overharvest Zone | Compensatory Zone(s) | Rest of Victoria | Interstate (NSW/SA) |
|---|---|---|---|---|
| 1. No Vic harvest | — | — | — | 15% |
| 2. Baseline 10% | 10% | 10% | 10% | 15% |
| 3. Overharvest 15% | 15% | 10% | 10% | 15% |
| 4. Compensatory (5/15%) | 15% | 5% | 10% | 15% |
| 5. Overharvest 20% | 20% | 10% | 10% | 15% |
| 6. Compensatory (5/20%) | 20% | 5% | 10% | 15% |

The assumed population vital rates in the models were the same as those described by Scroggie and Ramsey (2020). A moderate 20% value for environmental stochasticity in the vital rates was assumed. As compensatory population dynamics are partially dependant on the dispersal of kangaroos from under-harvested to over-harvested areas, we considered three alternative scales of dispersal to assess sensitivity of the model to this parameter. Dispersal was therefore modelled using an exponential dispersal kernel, with scale parameters of 10, 20 and 50 km. Knowledge regarding carrying capacities (and hence density-dependent population dynamics) for Victorian kangaroo populations is very limited, and the dynamics of the spatial harvest model are known to be highly sensitive to assumptions about carrying capacity (Scroggie and Ramsey, 2020). We therefore considered three alternative carrying capacities, based on the carrying capacity being 1, 2 and 4 times the spatialised estimates of GK abundance in Scroggie and Ramsey (2020). The model described by Scroggie and Ramsey used square grid cells, each 50 $\times$ 50 km. As the model presented here requires finer spatial resolution to determine expected population trajectories within individual harvest zones, we altered the structure of the model to reduce the cell size to 25 $\times$ 25 km. While this refinement allows more spatially accurate predictions of abundance, it comes at the cost of a greater computational burden, resulting in significantly increased execution times for the model.

For each combination of species (EGK or WGK), dispersal (10, 20 or 50 km) and carrying capacity (1, 2 or 4 times current abundance) we ran 200 stochastic population simulations over 50 years. For each simulation the minimum abundance of the population was recorded as a measure of ecological risk, on the basis that regular excursions into low abundance states are indicative of high risks of population extinction. These simulated minimums were recorded both for the total Victorian population (but excluding Gippsland for EGKs), and for the populations within the over-harvested zones (Mallee and North East).

To assess the relative risk, we first calculated the 5th percentile of population minimums under the currently recommended 10% harvest rate (based on 200 stochastic simulations) as a baseline measure of ecological risk. For all remaining harvest scenarios, we then estimated the proportion of stochastic population trajectories that had minimum abundances less than this baseline. This approach enabled comparisons of relative ecological risk to be made across the various scenarios, thereby allowing assessments of risk relative to the intended baseline harvest rate of 10% Victoria-wide.

## 2.4 Apportioning the quota between the KHP and ATCW permits

Once the predicted demand for kangaroos authorised under the ATCW permit process was estimated, the total recommended sustainable offtake of WGK and EGK for 2021 was apportioned between the predicted ATCW demand and the KHP by subtracting the predicted ATCW demand from the total quota. Where the predicted demand exceeded the recommended total level of take, the resulting KHP quota was reduced to zero. The KHP allocation was then further revised to ensure the total offtake (KHP + ATCW) did not exceed the total recommended sustainable offtake for the state.

# 3 Results

## 3.1 Kangaroo abundance

The abundance estimates for the three kangaroo species in each harvest zone during 2020 are given in Table 3, these being derived by aggregation of the LGA-level results presented in Moloney *et al*. (2020). The trends in kangaroo abundance since aerial surveys began in 2017 indicates that kangaroo populations have generally increased since the last survey in 2018 with an approximate 41% (95% CI; 22% to 60%) increase in EGK and a 12% (95% CI; –3% to 27%) increase in WGK, across the state. However, populations in the Mallee and North East zones have exhibited slight declines since 2018 (Figure 2). Based on these estimates, the annual quota for GKs for 2021, using a maximum proportional offtake of 10%, is given in Table 4.

**Table 3. Kangaroo abundances in seven harvest zones covering the non-forested part of Victoria, estimated from aerial surveys in October 2020. Estimates are rounded to the nearest 50.**

| Harvest Zone | Red Kangaroo | Eastern Grey Kangaroo | Western Grey Kangaroo | Grey Kangaroos Combined |
|---|---|---|---|---|
| Mallee | 30,450 | 4,550 | 32,750 | 37,300 |
| Upper Wimmera | | 65,300 | 72,800 | 138,100 |
| Lower Wimmera | | 387,800 | 39,900 | 427,700 |
| Central | | 658,950 | | 658,950 |
| Otway | | 236,950 | | 236,950 |
| North east | | 239,850 | | 239,850 |
| Gippsland | | 172,700 | | 172,700 |
| **Statewide Total** | **30,450** | **1,766,100** | **145,450** | **1,911,550** |

**Table 4. Recommended total take for Grey Kangaroos for 2021 by harvest zone.**

Totals include all predicted culling under both ATCW and commercial harvesting allocations for the period 1st January to 31st December 2021. Quotas are set at 10% of the population per annum and are rounded to the nearest 50.

| Harvest Zone | Eastern Grey Kangaroo | Western Grey Kangaroo | Grey Kangaroos Combined |
|---|---|---|---|
| Mallee | 450 | 3,250 | 3,700 |
| Upper Wimmera | 6,550 | 7,300 | 13,850 |
| Lower Wimmera | 38,800 | 4,000 | 42,800 |
| Central | 65,900 | | 65,900 |
| Otway | 23,700 | | 23,700 |
| North east | 24,000 | | 24,000 |
| Gippsland | 17,250 | | 17,250 |
| **Statewide Total** | **176,650** | **14,550** | **191,200** |

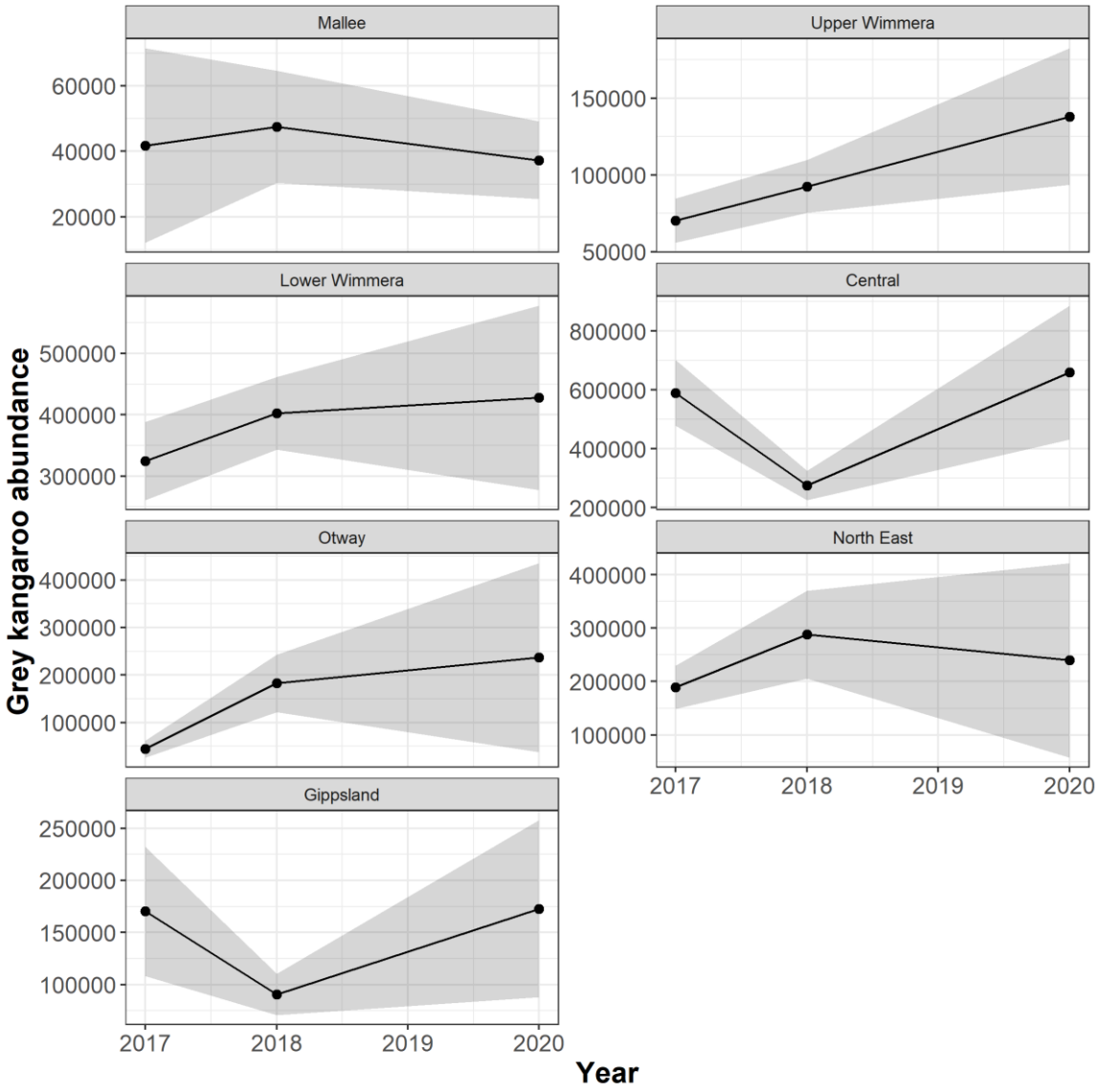


**Figure 2. Trends in the abundance of Grey Kangaroos in each harvest zone since aerial surveys began in 2017. Grey shading indicates 90% confidence intervals.**

## 3.2 Predicting demand for Kangaroos taken under ATCW permits

Based on the MASE accuracy measure, the ARIMA model including both autoregressive and moving average components was generally the preferred model for ATCW numbers having better predictive accuracy than the ETS model (Table 5). However, the ETS model had better predictive accuracy for ATCW numbers in the Mallee and North East zones. To capture model uncertainty, we used model averaged estimates from both the ETS and ARIMA models (with equal weighting) to predict ATCW demand in 2021 (Figure 3). However, predictions were rather imprecise for some zones (Figure 3).

Generally, numbers of kangaroos predicted to be taken under ATCW permits are lower than the total quota for each zone, with the exception of the Mallee and North East zones where ATCW numbers are predicted to be around 15% and 17% of the population, respectively (Table 6). These predictions are similar to the average offtake observed over the last three years as a percentage of the average population abundance (Table 6).

**Table 5. Predictive accuracy expressed as the mean absolute scaled error (MASE) for four models fitted to the time series of ATCW permit numbers between 2002 and 2019. Lower values (bolded) indicate models with better predictive accuracy.**

| Zone | ETS | ARIMA |
|---|---|---|
| Mallee | **0.83** | 0.85 |
| Upper Wimmera | 1.04 | **0.87** |
| Lower Wimmera | 0.97 | **0.76** |
| Central | 0.99 | **0.87** |
| Otway | 0.79 | **0.60** |
| North East | **0.86** | 0.94 |
| Gippsland | 0.74 | **0.71** |

**Table 6. The recommended total quota of grey kangaroos for 2021 compared with the predicted ATCW numbers from the best fit ARIMA model. The offtake (%) indicates the predicted ATCW numbers in 2021 as a percentage of the kangaroo abundance in the zone. The 3-year average is the equivalent calculation averaged over the last three years (2017–2019).**

| Zone | Total quota | Predicted ATCW | Offtake (%) | Offtake (%) 3-year average |
|---|---|---|---|---|
| Mallee | 3,700 | 5,543 | 14.9 | 18.7 |
| Upper Wimmera | 13,850 | 3,051 | 2.2 | 3.0 |
| Lower Wimmera | 42,800 | 15,729 | 3.7 | 3.7 |
| Central | 65,900 | 45,487 | 6.9 | 6.6 |
| Otway | 23,700 | 3,997 | 1.7 | 2.6 |
| North East | 24,000 | 40,304 | 16.8 | 14.5 |
| Gippsland | 17,250 | 5,243 | 3.0 | 3.7 |
| **Total** | **191,200** | **119,353** | **7.0** | **6.5** |

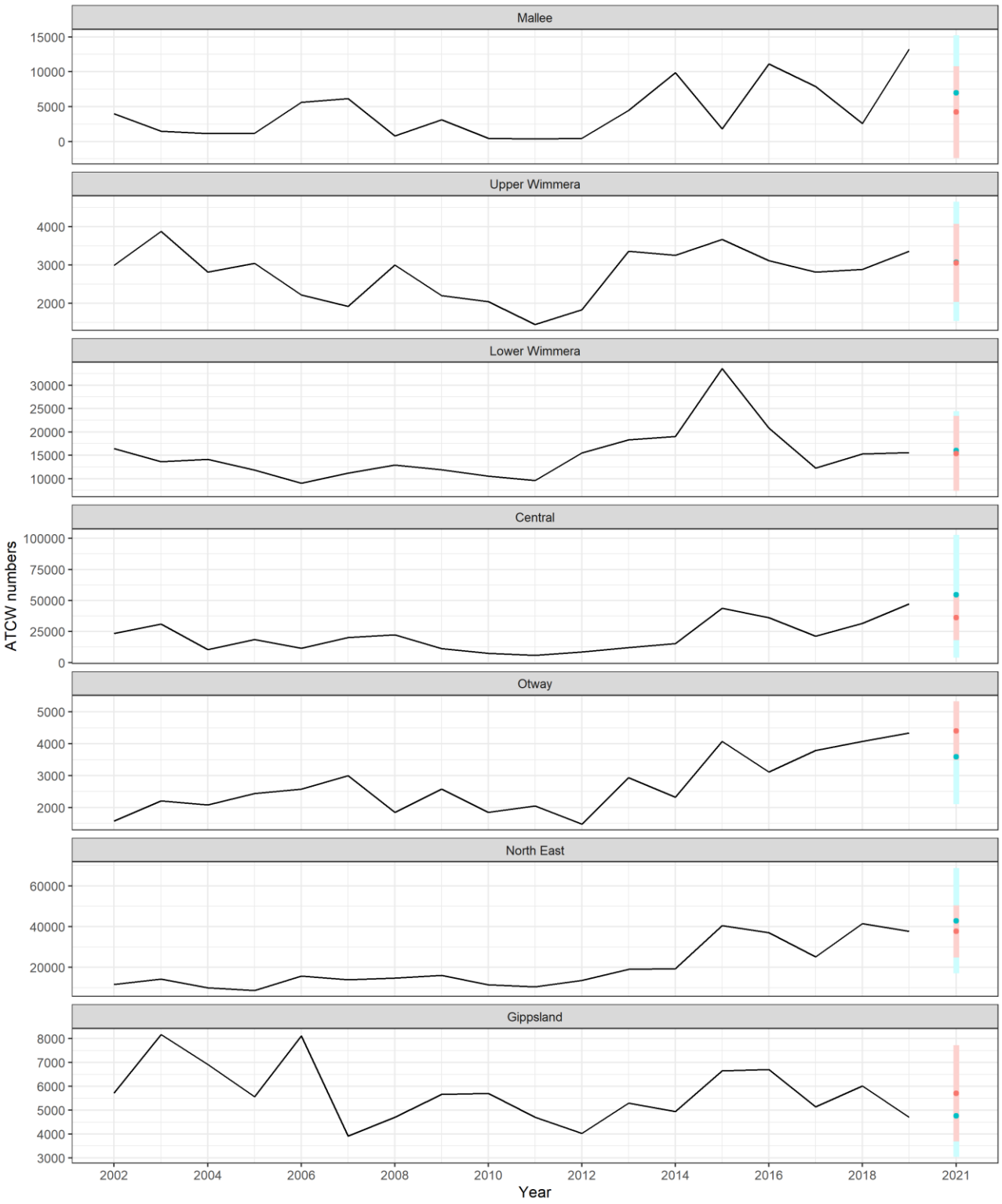


**Figure 3. Time series of kangaroos taken under ATCW permits for each harvest zone from 2002 to 2019. The predicted ATCW numbers for 2021 (± 90% confidence interval) are that predicted by the ETS model (blue circle and shading) and the ARIMA model (red circle and shading). Data for 2020 was excluded from the model fitting because it was incomplete.**

## 3.3 Sustainability of variable harvest rates among zones

### 3.3.1 Risk analysis for harvest management of Western Grey Kangaroos in the Mallee harvest management zone

Estimates of relative ecological risk of the various harvest management scenarios for Western Grey Kangaroos in Victoria are given in Figure 4. For the Mallee harvest management zone only (top panel of Figure 4), it is apparent that both overharvesting regimes (15 and 20%, red columns) have markedly higher relative ecological risks than the baseline 10% harvest regime (blue column). When compensatory under-harvesting (5%) was applied in the adjacent Upper and Lower Wimmera harvest zone, ecological risks for the Mallee population were reduced somewhat (pink columns), but still remained markedly higher than was the case under a baseline 10% harvest scenario.

When the entire Victorian population of WGKs was considered (rather than the Mallee population alone), relative ecological risks were lower for all scenarios (Figure 4, bottom panel). However, the overharvesting scenarios (15% and 20% overharvest in the Mallee) still entailed a higher risk of the population going below the threshold abundance, relative to the baseline 10% harvesting scenario. When compensatory under-harvesting (5 %) was applied in the Upper and Lower Wimmera zones the risks to the populations as whole were substantially mitigated (pink columns).

Collectively, these results provide some tentative support for the notion that under-harvesting in the Upper and Lower Wimmera could offset the impacts of overharvesting in the Mallee on the entire population of WGKs in Victoria. However, when the Mallee population of WGKs is considered in isolation, it would seem that compensatory under-harvesting in adjacent zones has little impact on ecological risk. This suggests that compensatory under-harvesting of WGKs in Victorian would function mainly to increase abundance of WGKs in the zones where under-harvesting is implemented (Upper and Lower Wimmera), but would do little to limit the reduction in abundances that would be expected in the over-harvested (Mallee) zone itself.

### 3.3.2 Risk analysis for harvest management of Eastern Grey Kangaroos in the North East harvest management zone

Results of a comparable risk analysis for EGKs in the North East harvest management zone are presented in Figure 5. For the North East zone only (top panel of Figure 5), it is apparent that risks of population trajectories falling lower than would be expected under the baseline 10% harvest rate are substantially higher for both overharvest (15% and 20%) scenarios (red columns). These added risks were not effectively mitigated by the imposition of a compensatory (5%) under-harvest in the adjacent Central zone (pink columns). Across all assumed values of dispersal and carrying capacity parameters, ecological risk was not substantially influenced by the assumed dispersal rate or carrying capacity of the EGK population.

Conversely, when considering the entire Victorian population of EGKs (but excluding the Gippsland zone; see methods), overharvest (15 or 20%, Figure 5, bottom panel, red bars) in the North East zone led to relatively small increases in ecological risk relative to a baseline constant harvest scenario at a rate of 10% (blue bars). This risk was somewhat mitigated when compensatory under-harvesting at a rate of 5% was applied in the Central zone (Figure 5, bottom panel, pink bars).

Collectively, the results of this risk analysis demonstrate some limited capacity for compensatory overharvesting in adjacent zones to reduce ecological risks for harvested populations of both species of grey kangaroos when the Victorian populations are considered in their entirety. However, the results also show that heightened ecological risks to the population in an overharvested management zone can continue in that zone and cannot be effectively mitigated by compensatory under-harvesting in an adjacent zone.

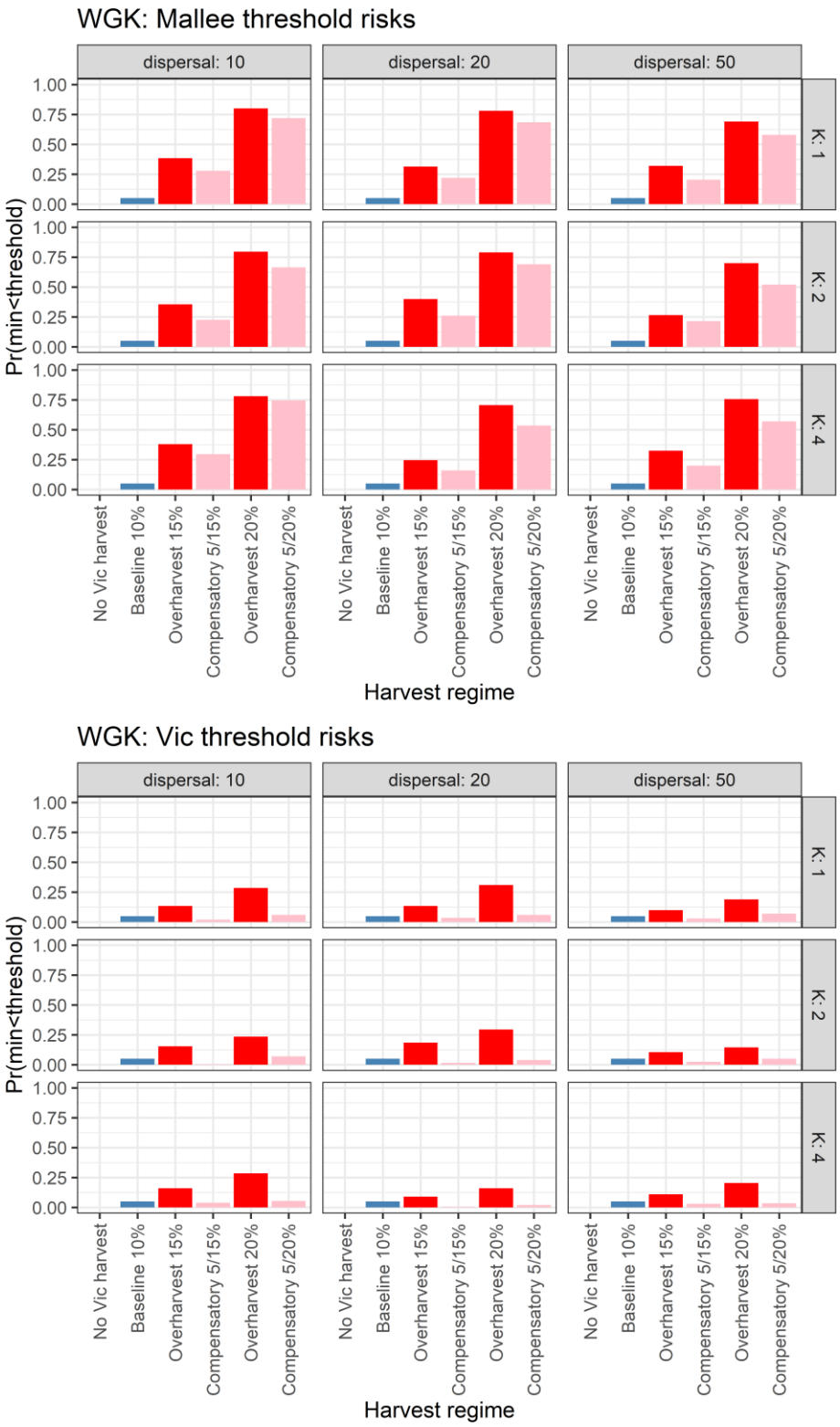


**Figure 4. Relative ecological risks for the five harvest management scenarios for Western Grey Kangaroos (WGK) in the Mallee harvest management zone (top), and for the whole of Victoria (bottom). Columns are the estimated probability that the population will drop below the 5% percentile of minimums that would be expected under a baseline (10% harvest management scheme). A larger magnitude implies a greater relative ecological risk. Each panel provides estimates under different combinations of assumed dispersal rates and carrying capacities for each of the 6 harvesting scenarios.**

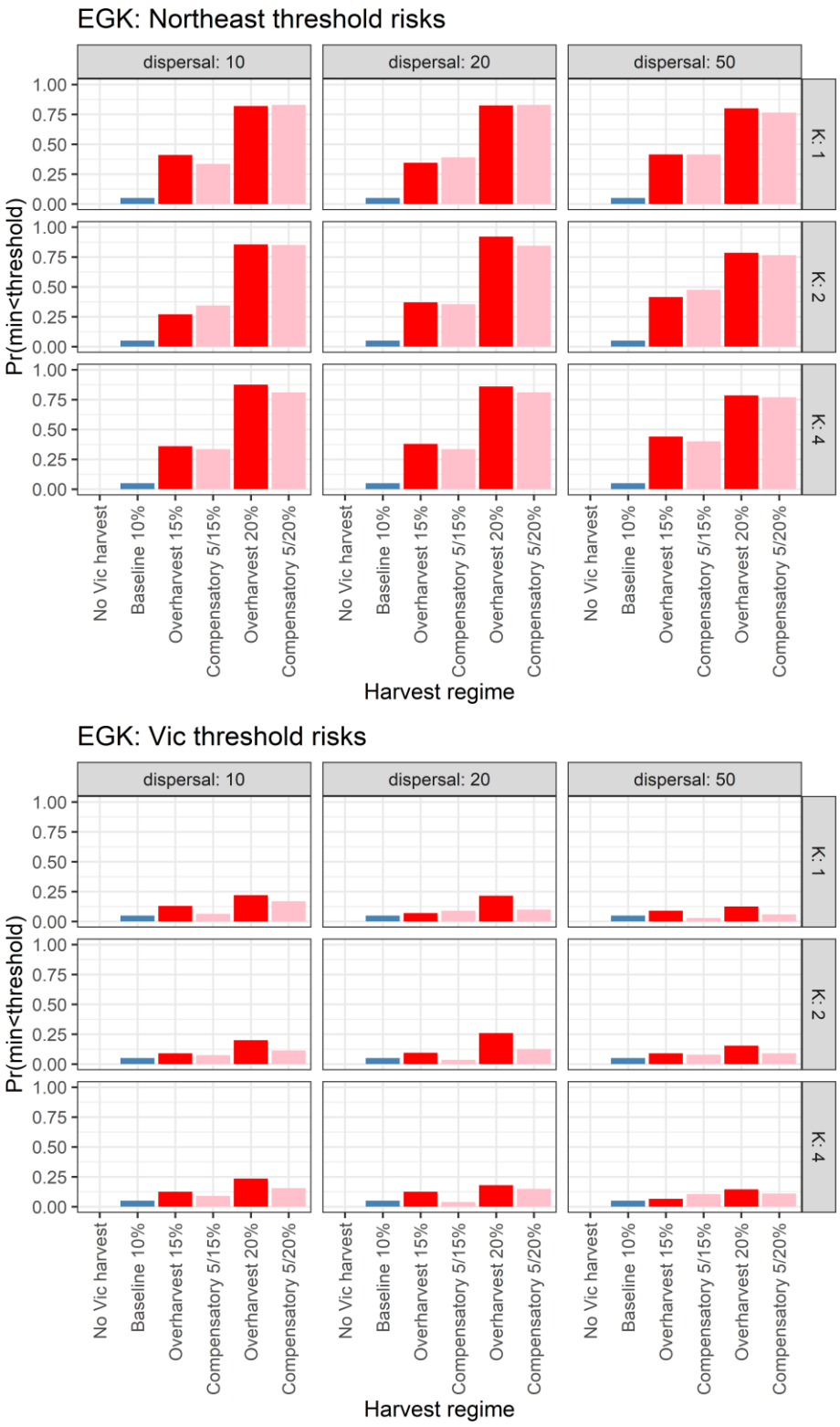


**Figure 5. Relative ecological risks for the 5 harvest management scenarios for Eastern Grey Kangaroos (EGK) in the North east harvest management zone (top), and for the whole of Victoria (excluding Gippsland, see methods, bottom). Columns are the estimated probability that the population will drop below the 5% percentile of minimums that would be expected under a baseline (10% harvest management scheme). A larger magnitude implies a greater relative ecological risk. Each of the grid of nine panel provides relative risk estimates under different combinations of assumed dispersal rates and carrying capacities (K) for the 6 harvesting scenarios (see methods).**

## 3.4 Apportioning the quota between the KHP and ATCW permits

Based on the calculation of the total quota for grey kangaroos for each harvest zone (Table 3) and the expected demand for ATCW permits in each zone for 2021 (Table 6 and Figure 2), the total quota was apportioned between the KHP and ATCW permit system (Table 7). Due to the high expected demand for ATCW permits in the Mallee and North East harvest zones, (which exceeds the total quota in these zones), the KHP quota has been reduced to 0 in these zones. The KHP was also reduced in other zones to ensure that the total offtake (KHP + ATCW) did not exceed the total quota for the state.

**Table 7. Recommended apportioning of quotas for Grey Kangaroos by ATCW and the KHP for 2021 by harvest zone. Values are rounded to the nearest 50.**

| Harvest Zone | Total Quota | Predicted ATCW | KHP quota |
|---|---|---|---|
| Mallee | 3,700 | 5,550 | 0 |
| Upper Wimmera | 13,850 | 3,050 | 9,000 |
| Lower Wimmera | 42,800 | 15,750 | 22,700 |
| Central | 65,900 | 45,500 | 16,400 |
| Otway | 23,700 | 4,000 | 15,700 |
| North east | 24,000 | 40,300 | 0 |
| Gippsland | 17,250 | 5,250 | 8,000 |
| **Subtotals** | | **119,400** | **71,800** |
| **Statewide Total** | | | **191,200** |

If a proportion of the kangaroo control predicted to occur under the ATCW system could, instead, be carried out by commercial harvesters under the KHP, the KHP quota could be adjusted accordingly, while still maintaining a sustainable level of take across the state. An alternative recommended quota accounting for a proportionate transfer from ATCW to KHP of 20% is outlined in Table 8.

**Table 8. Alternative recommended apportioning of quotas for Grey Kangaroos by ATCW and the KHP for 2021 by harvest zone, assuming 20% of predicted ATCW control is undertaken through the KHP.**

| Harvest Zone | Total Quota | Adjusted ATCW prediction | Adjusted KHP quota |
|---|---|---|---|
| Mallee | 3,700 | 4,440 | 1,110 |
| Upper Wimmera | 13,850 | 2,440 | 9,610 |
| Lower Wimmera | 42,800 | 12,600 | 25,850 |
| Central | 65,900 | 36,400 | 25,500 |
| Otway | 23,700 | 3,200 | 16,500 |
| North east | 24,000 | 32,240 | 8,060 |
| Gippsland | 17,250 | 4,200 | 9,050 |
| **Subtotals** | | **95,520** | **95,680** |
| **Statewide Total** | | | **191,200** |

# 4 Conclusions

Compared with the estimates from the previous aerial survey in 2018, kangaroo abundance in 2020 is greater, with an approximate 41% (95% CI; 22% to 60%) increase in EGK and a 12% (95% CI; –3% to 27%) increase in WGK across the state. However, changes in abundance varied across harvest zones, with populations in both the Mallee and North East zones declining from the 2018 estimates. Coincidently, these are also the two zones where historical and predicted ATCW offtake, as a proportion of estimated abundance, has been greatest.

Over the previous four years, since the start of kangaroo aerial surveys, the number of kangaroos authorised on ATCW permits amounted to an average offtake of 14.5% and 18.7% of the populations in the North East and Mallee zones, respectively. This level of offtake is greater than the 10% currently recommended as sustainable, and hence the kangaroo populations in these zones are at risk of overharvesting. Continued offtake at these levels could lead to lower population levels in the future (Scroggie and Ramsey 2020). This issue may be more acute for the Mallee zone, which contains a large proportion of the Victorian WGK population. We have therefore recommended that no KHP quota be issued for 2021 for the Mallee and North East zones (Table 7). However, assuming that 20% of the kangaroo control predicted under the ATCW system was instead undertaken by commercial harvesters under the KHP, some KHP quota may be allocated to these zones (Table 8). Regardless of which recommended quota is adopted (Table 7 or 8), the quota allocation across all zones has been adjusted to ensure that the total take across the state remains sustainable. The overall 2021 KHP quota is considerably higher than the 2020 quota, reflecting the overall higher kangaroo abundance.

In future, it would be desirable for the majority of kangaroos that would otherwise be culled under ATCW permits to be commercially harvested through the KHP, as this would enable more accurate tracking of the total take of kangaroos. In addition, increased use of the KHP should lead to less wastage of carcases, improved animal welfare outcomes, and economic benefits for the state's commercial kangaroo harvesters. However, it is acknowledged that the KHP is a new program that is still maturing in Victoria, and landholder awareness of this option is low. We therefore recommend that the KHP be encouraged and promoted as an alternative option to landholders for kangaroo control.

Risk analyses of scenarios where harvest rates greater than 10% were permitted in some zones, with compensatory reductions in harvesting (5%) in adjacent management zones, has demonstrated that compensatory under-harvesting can help to reduce the risks of population decline for Victorian populations of both species of Grey Kangaroo as a whole. However, it is important to recognize that this approach runs the risk of causing potentially unacceptable depletions in the abundances of Grey Kangaroos within the zones that are subjected to higher rates of harvesting (15 or 20%), even if the strategy limits the depletion of the populations as a whole. These risks are only slightly mitigated by reducing harvest rates in adjacent zones, even when the assumed rates of dispersal between harvest management zones are at the higher end of the plausible range.

Such risks (regional population depletion) must be considered more serious for populations of Western Grey Kangaroos, which are at the edge of their geographic range in the north-west of the state and thus have much more limited capacity for recovery in the event of population depletion through over harvesting.

## Recommendations

- For the 2021 calendar year, a total of 191,200 Grey Kangaroos is recommended as the maximum sustainable offtake. This includes kangaroos taken in the commercial harvest program (KHP) and through ATCW permits. The sustainable kangaroo offtake in each harvest management zone, apportioned between the KHP and ATCW permit process, is shown in Table 7.
- It would be desirable for the majority of kangaroos that would otherwise by authorised through ATCW permits to be commercially harvested through the KHP, as this would enable more accurate tracking of the total take of kangaroos. In addition, increased use of the KHP should lead to less wastage of carcases, improved animal welfare outcomes, and economic benefits for the state's commercial kangaroo harvesters.
- If a proportion of the kangaroo control predicted to occur under the ATCW system could, instead, be carried out by commercial harvesters under the KHP, the KHP quota could be adjusted accordingly, while still maintaining a sustainable level of take across the state. An alternative recommended quota accounting for a proportionate transfer from ATCW to KHP of 20% is outlined in Table 8.

- If reallocation of a proportion of predicted ATCW control to the KHP cannot occur in the Mallee harvest management zone, no commercial harvest is recommended in this zone during 2021 to protect Western Grey Kangaroo populations in the region from potential overharvesting. Reducing harvest rates for Western Grey Kangaroos in the Upper and Lower Wimmera zones will not compensate for overharvesting in the Mallee zone, but it will mitigate the risks on the Western Grey Kangaroo population as a whole.
- If reallocation of a proportion of predicted ATCW control to the KHP cannot occur in the North East zone, no commercial harvest is recommended in this zone for 2021 to protect Eastern Grey Kangaroos in the region from potential overharvesting. Reducing harvest rates on Eastern Grey Kangaroos in the adjacent Central zone will not compensate for overharvest in the North East zone but will mitigate the risks on the Eastern Grey Kangaroo population as a whole.
- Kangaroos authorised to be taken through the ATCW permit process should be carefully monitored in both the Mallee and North East harvest zones to ensure demand does not exceed the maximum recommended sustainable offtake.
- Accurate and detailed harvest records, including the location, species, sex, and age class of all harvested kangaroos should be maintained. This is especially important for the Upper and Lower Wimmera harvest zones, so that the numbers of harvested Western and Eastern Grey Kangaroos from those harvest zones can be accurately assessed.

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