Kangaroo harvest quotas for Victoria, 2022

D.S.L. Ramsey and M.P. Scroggie

November 2021

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 334

Arthur Rylah Institute for environmental research

VICTORIA State Government | Environment, Land, Water and Planning

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.

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

Citation: Ramsey, D.S.L. and Scroggie, M.P. (2021). Kangaroo harvest quotas for Victoria, 2022. *Arthur Rylah Institute for Environmental Research Technical Report Series* No. 334. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Front cover photo: Eastern Grey Kangaroo (Source: WorldAtlas.com).

Edited by David Meagher, Zymurgy SPS

ISSN 1835-3827 (print)
ISSN 1835-3835 (pdf))
ISBN 978-1-76105-831-8 (print)
ISBN 978-1-76105-832-5 (pdf/online/MS word)

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au or contact us via the National Relay Service on 133 677 or www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au

Kangaroo harvest quotas for Victoria, 2022

D.S.L. Ramsey and M.P. Scroggie

Arthur Rylah Institute for Environmental Research
123 Brown Street, Heidelberg, Victoria 3084

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 334

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
Heidelberg, Victoria

Acknowledgements

We thank Bali Forbes for providing us with the historical data on the numbers of kangaroos culled under the Authority to Control Wildlife and Kangaroo Harvest Program, which are used in this report. We thank Lola Jones, Bali Forbes (Biodiversity Division) and Justin Cally (ARI) for providing helpful comments on drafts of this report. This work was funded by the Biodiversity Division, Department of Environment, Land, Water and Planning, Victoria.

Contents

Tables

Figures

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 the overexploitation of kangaroo populations.

Aims:

Use a kangaroo harvest model to project the abundance of grey kangaroos for the end of the 2021 calendar year, in order to recommend a maximum sustainable offtake of Eastern and Western Grey Kangaroos for 2022 and apportion the total take between the Authority to Control Wildlife (ATCW) permit process and the commercial Kangaroo Harvest Program (KHP).

Methods:

Projections of grey kangaroo abundance used the monitoring data from the statewide aerial survey of kangaroos undertaken in 2020 as a starting point, allowing for grey kangaroo take during the intervening period from both the KHP and ATCW permit process. The annual total recommended take for 2022 was set at 10% of the projected abundance. The predicted demand for grey kangaroos under the ATCW permit process in 2022 was estimated by analysing the historical ATCW grey kangaroo numbers using time-series models. The total take was then apportioned between the expected demands for both ATCW permits and the KHP.

Results:

The total recommended take for 2022 was assessed as 185,850 grey kangaroos, comprising 167,350 Eastern Grey Kangaroos and 18,500 Western Grey Kangaroos. Predicted demand for grey kangaroos under the ATCW permit process was estimated to be 72,500 comprising approximately 39% of the total take for 2022. However, demand in the Mallee and North East harvest management zones was predicted to exceed the recommended take in those zones. This left an allocation of 113,350 grey kangaroos for the KHP, after adjusting for the total predicted ATCW demand.

Conclusions and implications:

The abundance of grey kangaroos projected at the end of 2021 was similar to the estimates from the 2020 aerial survey, and hence total sustainable take for 2022 was also similar to 2021. Given that insufficient survey data exist to calibrate the kangaroo harvest model, consideration could be given to setting quotas for years where no surveys are undertaken, based on the most recent aerial survey estimates after adjusting for the projected uptake of ATCW permits. This should be coupled with an annual review to assess whether modifications to the quota might be required, based on current environmental conditions. The above system for setting quotas for years when no aerial surveys are undertaken could continue until sufficient survey data accumulate to calibrate the kangaroo harvest model, which is likely to require at least eight surveys for adequate calibration.

Demand for grey kangaroos taken under ATCW permits for 2022 was predicted to be lower than in 2021, resulting in a higher allocation for the KHP. However, the number of grey kangaroos taken under ATCW permits in both the Mallee and North East zones was predicted to be higher than the total recommended take. Consequently, no KHP quota has been recommended for the Mallee or the North East zone, although recommendations for the transfer of a proportion of the ATCW allocation to the KHP have been provided.

Recommendations:

- For the 2022 calendar year, a total take of 185,850 grey kangaroos is recommended under the commercial harvest program (KHP) and ATCW permits. The total sustainable take of grey kangaroos in each harvest management zone, apportioned between the KHP and ATCW permit process, is shown in Table 7 on page 11.
- Until sufficient aerial survey data accumulate to calibrate the kangaroo harvest model, consideration could be given to setting quotas for years where no surveys are undertaken based on the most recent aerial survey estimates, after adjusting for the projected uptake of ATCW permits. This should be

coupled with an annual review to assess whether modifications to the quota might be required, based on current environmental conditions.

- It would be desirable for the majority of grey kangaroos that would otherwise be taken 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 carcasses, improved animal welfare, and economic benefits for the state's commercial kangaroo harvesters.
- If a proportion of the predicted grey kangaroo taken 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 on page 12.
- The number of grey kangaroos authorised to be taken through the ATCW permit process should be carefully monitored in both the Mallee and North East harvest zones. If demand exceeded expectations, the KHP quota would have to be adjusted to ensure the total take did not exceed the recommended sustainable take.
- 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 2021-2023* (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 recommended take 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 kangaroo populations in the state, it is essential that the maximum number of kangaroos that are permitted to be taken under the KHP and ATCW 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 rates 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 recommended take is divided between seven harvest management zones, based on the proportion of the total state population in each zone. Because the total take for each harvest zone includes take through both the KHP and ATCW, the regulatory framework needs to include mechanisms for apportioning the total take between these two categories.

The 10% total recommended take of kangaroos recommended by Scroggie and Ramsey (2019) is conservative; total take in other states is typically set at 15% (Hacker *et al.* 2004; McLeod *et al.* 2004). However, the 10% take 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 calibrate 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 the commercial harvest of kangaroos through the KHP for the 2022 calendar year. This analysis is based primarily on projections of the kangaroo population using the most recent monitoring data from the statewide aerial survey of kangaroos as a starting point (Moloney *et al.* 2021), allowing for kangaroo take during the intervening period from both the KHP and ATCW permit process. We then used historical ATCW permit information to predict the likely demand for kangaroo ATCW permit numbers in 2022 and used these to adjust the KHP quotas for each harvest zone.

2 Methods

2.1 Kangaroo abundance estimates

Moloney *et al*. (2017; 2018; 2021) 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 (excluding metropolitan Melbourne). 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 WGK; 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.* 2021). 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.

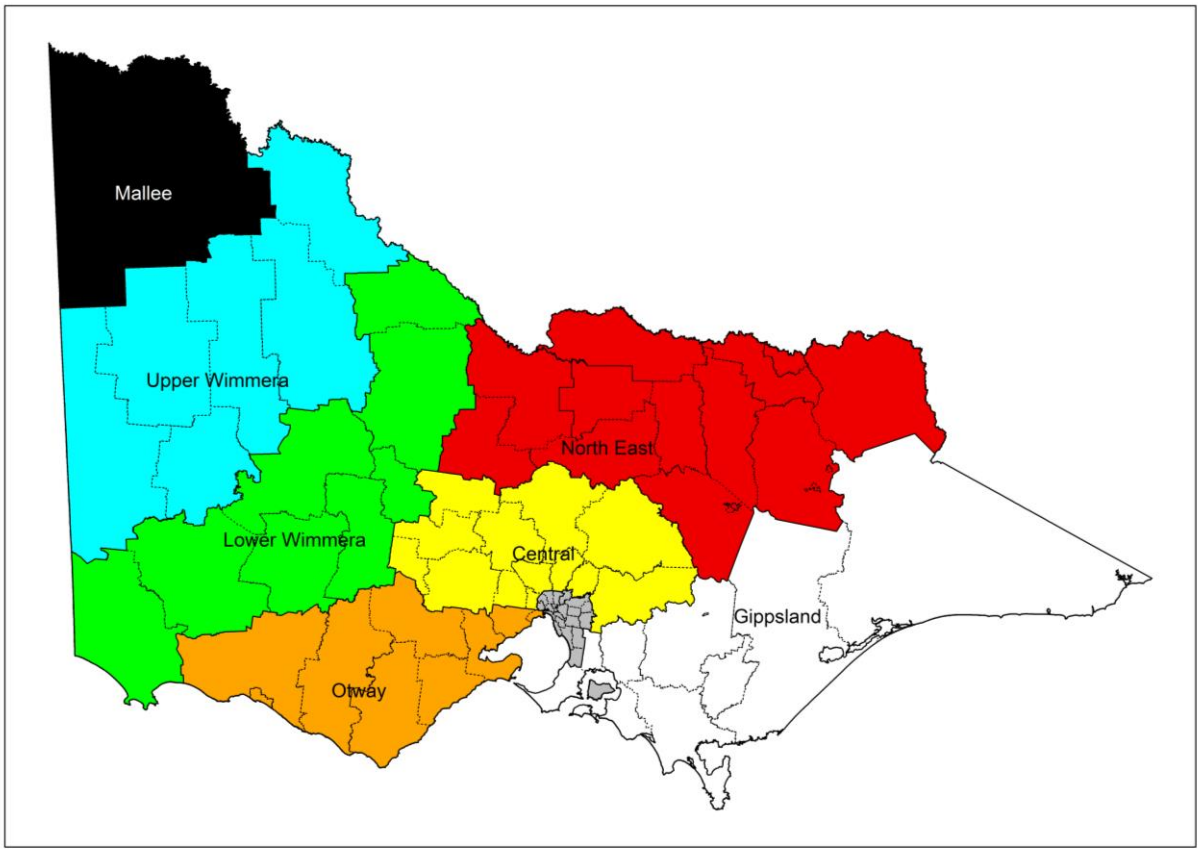

Figure 1. Kangaroo harvest management zones in Victoria. Each zone is formed by amalgamating groups of ecologically similar local government areas. The grey shaded areas are not subject to harvest. Colour-coding of harvest management areas matches the colours of the tags attached to carcasses during 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 were undertaken in the seven harvest management zones 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 (Moloney *et al.* 2021).

2.2 Estimating harvest quotas for 2022

Estimates of the grey kangaroo population in each harvest zone from the 2020 aerial survey were projected forward one year to provide population estimates for end of the 2021 calendar year. The population in each zone was forecast using a simple aspatial, density-dependent population model with harvesting included. This model is analogous to the more complex age-structured, spatial harvest model used by Scroggie and Ramsey (2020) to model harvested grey kangaroo populations in Victoria. As the desired predictions are aspatial and do not require age-structure information, the additional complexity of a spatially explicit or age-structured model was unnecessary, and in any case would be expected to result in broadly congruent population forecasts.

The population model for changes over time in total abundance within a given stratum (N_t), was

$$N_t \sim Poisson(\mu_t)$$
$$\mu_t = (N_{t-1}e^{r_t}) - H_t \qquad \text{Equation 1.}$$
$$r_t = r_m \frac{K - N_{t-1}}{K} + \epsilon_t$$
$$\epsilon_t \sim N(0, \sigma)$$

where:

r_m is the maximum rate of increase of a grey kangaroo population at near-zero density

K is the carrying capacity of the population

H_t is the number of kangaroos harvested in year t

ϵ_t are normally distributed errors with standard deviation σ to account for underlying environmental stochasticity in the population vital rates.

Demographic stochasticity was accommodated in the model by setting the number of animals in successive years as a random draw from a Poisson distribution, with parameters defined by the expected population size μ_t.

The model was parameterised using available data and expert opinion (e.g. Scroggie and Ramsey 2020). Initial population sizes for 2020 from each harvest zone were based on the results of the most recent aerial and ground surveys (Moloney *et al.* 2021). For simplicity, only the point estimates of abundance were used in the forward projection process to forecast the population to the end of 2021.

The kangaroo take in each harvest zone from both ATCW permits and the KHP during 2021 were complete up to September 30 2021. The total take for the calendar year was then inferred by increasing the numbers of ATCW permits issued and KHP allocated by one quarter, assuming the rate of uptake was similar to the previous three quarters, to accommodate the remaining portion of the calendar year.

The uncertain parameters in the model were the maximum rate of increase r_m, the carrying capacity K and the environmental stochasiticity σ. Uncertainty in each of these parameters was described in the model by assigning each a probability distribution from which random draws were made. For each replicate set of random parameter values, the population was projected forward one year to forecast the population size at the end of 2021.

The following distributions were assumed:

- The maximum rate of increase r_m was specified on a proportional increase scale λ_m, rather than the original logarithmic scale used in the model above (i.e. $\lambda_m = e^{r_m}$).
- A normal distribution of values described the uncertainty in λ_m with a mean of 1.2 (i.e. 20% annual maximum rate of increase) and a standard deviation of 0.05. This is in accordance with the range of values of r_m implied for the age-structured model of Scroggie and Ramsey (2020).

There is very little available data to inform carrying capacity estimates (K) for Victorian kangaroo populations. As a conservative approach, we assumed that the carrying capacity in each zone was somewhere in the range of 80% to 200% of the current abundance. Assuming a low carrying capacity, and hence limited capacity for population increase, is a conservative approach and will tend to result in lower population forecasts in the short term.

There is also little available data to inform the parameterisation of the environmental stochasticity parameter (σ). We therefore specified a broad range of values uniformly distributed between 0 and 0.15 for this parameter.

A sample of 10,000 parameter combinations was drawn from the above probability distributions, and the population was then projected forward one year. The resulting mean of the 10,000 forecasts was taken to represent the most likely abundance for the end of the 2021 calendar year and was used to set the total recommended take for the 2022 calendar year set at 10% of the mean abundance estimates. Estimates of uncertainty in the forecast (95% confidence intervals) were also calculated to illustrate uncertainty in the population projections. The total recommended take for grey kangaroos were then apportioned between Western Grey Kangaroos and Eastern Grey Kangaroos using the estimate of species composition derived from ground surveys in those zones where the two species overlap (Moloney *et al.* 2021).

2.3 Predicting demand for grey 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 September 30, 2021. As mentioned in section 2.2, the total take for the 2021 calendar year was estimated by imputing ATCW permits and the KHP uptake for the final quarter of the year.

We modelled the historical time series of ATCW numbers for each zone using an exponential smoothing state-space (ETS) model (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). Model-averaged estimates of the ETS and ARIMA models for each zone were then used to predict the likely number of kangaroos authorised under ATCW permits for the 2022 calendar year.

Once the predicted demand for kangaroos authorised under the ATCW permit process for 2022 was estimated, the total recommended take of WGK and EGK for 2022 was apportioned between the predicted ATCW demand and the KHP by subtracting the predicted ATCW demand from the total take, separately for each harvest zone. Where the predicted demand of ATCW permits exceeded the total recommended take, the resulting KHP quota was reduced to zero. The KHP quota was then further revised to ensure the total take (KHP + ATCW) did not exceed the total recommended take for the state.

3 Results

3.1 Harvest quotas for 2022

The forecast abundance of grey kangaroos in each harvest zone at the end of 2021 predicted by the model (Equation 1) were little changed from those derived from the 2020 aerial surveys, although confidence limits were broad (Table 2). This reflects the high uncertainty in the input parameters, which was related to the limited survey data available to inform the parameterisation of the model. Generally, the predictions indicated small declines (< 5%) in abundance from the 2020 survey in most zones, and less than 3% decline overall. The exception was the North East zone, where an approximate 8% decline was predicted (Table 2). However, the confidence intervals for these estimated changes were also broad, indicating a high uncertainty about the actual change (Table 2).

Forecast totals take of grey kangaroos for all zones other than the North East are predicted to be less than the nominal 10% recommended total (Table 3). In the North East, the total take is forecast to reach slightly more than 12% of the total population (Table 3). As predicted abundances of grey kangaroos have not changed greatly, a total take for each zone very close to those specified for the 2021 calendar year are also recommended for 2022 (Table 4).

Table 2. Kangaroo abundances in seven harvest zones covering the non-forested part of Victoria, estimated from aerial surveys in 2020 (Survey), and predicted at the end of 2021 using the kangaroo harvest model (Predicted). LCL, UCL – lower and upper 95% confidence intervals for the predicted abundances. % Change – percentage change from 2020 survey (± 95% confidence intervals). Estimates are rounded to the nearest 50.

Harvest Zone	Survey (2020)	Predicted (2021)	LCL	UCL	% Change
Mallee	37,300	36,200	29,050	44,300	–2.9 (–22, 19)
Upper Wimmera	138,100	133,450	106,900	164,100	–3.4 (–23, 19
Lower Wimmera	427,700	410,400	325,700	508,150	–4.1 (–24, 19)
Central	658,950	650,550	524,100	799,250	–1.3 (–21, 21)
Otway	236,950	235,900	189,750	291,000	–0.4 (–20, 23)
North East	239,850	221,100	173,500	275,100	–7.8 (–28, 15)
Gippsland	172,700	170,550	136,200	209,700	–1.3 (–21, 21
Statewide Total	**1,911,550**	**1,858,150**	**1,485,200**	**2,291,600**	**–2.8 (–22, 20)**

Table 3. Forecast kangaroo take from the KHP and ATCW permit process during 2021 and the estimated take as a percentage (%) of the 2020 kangaroo abundance.

Harvest Zone	ATCW	KHP	Total	%
Mallee	1,773	1,093	2,867	7.7
Upper Wimmera	2,148	9,267	11,415	8.3
Lower Wimmera	12,589	25,493	38,083	8.9
Central	14,712	25,493	40,205	6.1
Otway	3,959	9,027	12,985	5.5
North East	22,381	8,027	30,408	12.7
Gippsland	3,829	6,933	10,763	6.2
Statewide Total	**61,391**	**85,333**	**146,726**	**7.7**

Table 4. Total recommended take of grey kangaroos in 2022 by harvest zone.

Totals include all predicted take under both ATCW and KHP allocations for the period 1 January – 31 December 2022. Recommended total takes are set at 10% of the population per year and are rounded to the nearest 50.

Harvest Zone	Eastern Grey Kangaroo	Western Grey Kangaroo	Grey Kangaroos Combined
Mallee	100	3,550	3,650
Upper Wimmera	5,050	8,300	13,350
Lower Wimmera	34,400	6,650	41,050
Central	65,050		65,050
Otway	23,600		23,600
North east	22,100		22,100
Gippsland	17,050		17,050
Statewide Total	**167,350**	**18,500**	**185,850**

3.2 Predicting demand for grey 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 because of its better predictive accuracy than the ETS model (Table 5). However, the ETS model had slightly better predictive accuracy for ATCW numbers in the Gippsland zone. To capture model uncertainty, we used model averaged estimates from both the ETS and ARIMA models (with equal weighting) to predict ATCW demand in 2022 (Figure 2). However, predictions were rather imprecise for some zones, such as the Mallee (Figure 2, Table 6).

Generally, numbers of grey kangaroos predicted to be taken under ATCW permits in 2022 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 11% of the population, respectively. However, predicted ATCW numbers for both these zones had high uncertainty (Table 6).

Table 5. Predictive accuracy expressed as the mean absolute scaled error (MASE) for two models fitted to the time series of ATCW permit numbers between 2002 and 2021. Lower values (bolded) indicate models with better predictive accuracy.

Zone	ETS	ARIMA
Mallee	0.79	**0.76**
Upper Wimmera	1.11	**0.85**
Lower Wimmera	1.10	**0.77**
Central	1.02	**0.82**
Otway	0.73	**0.67**
North East	0.98	**0.95**
Gippsland	**0.74**	0.80

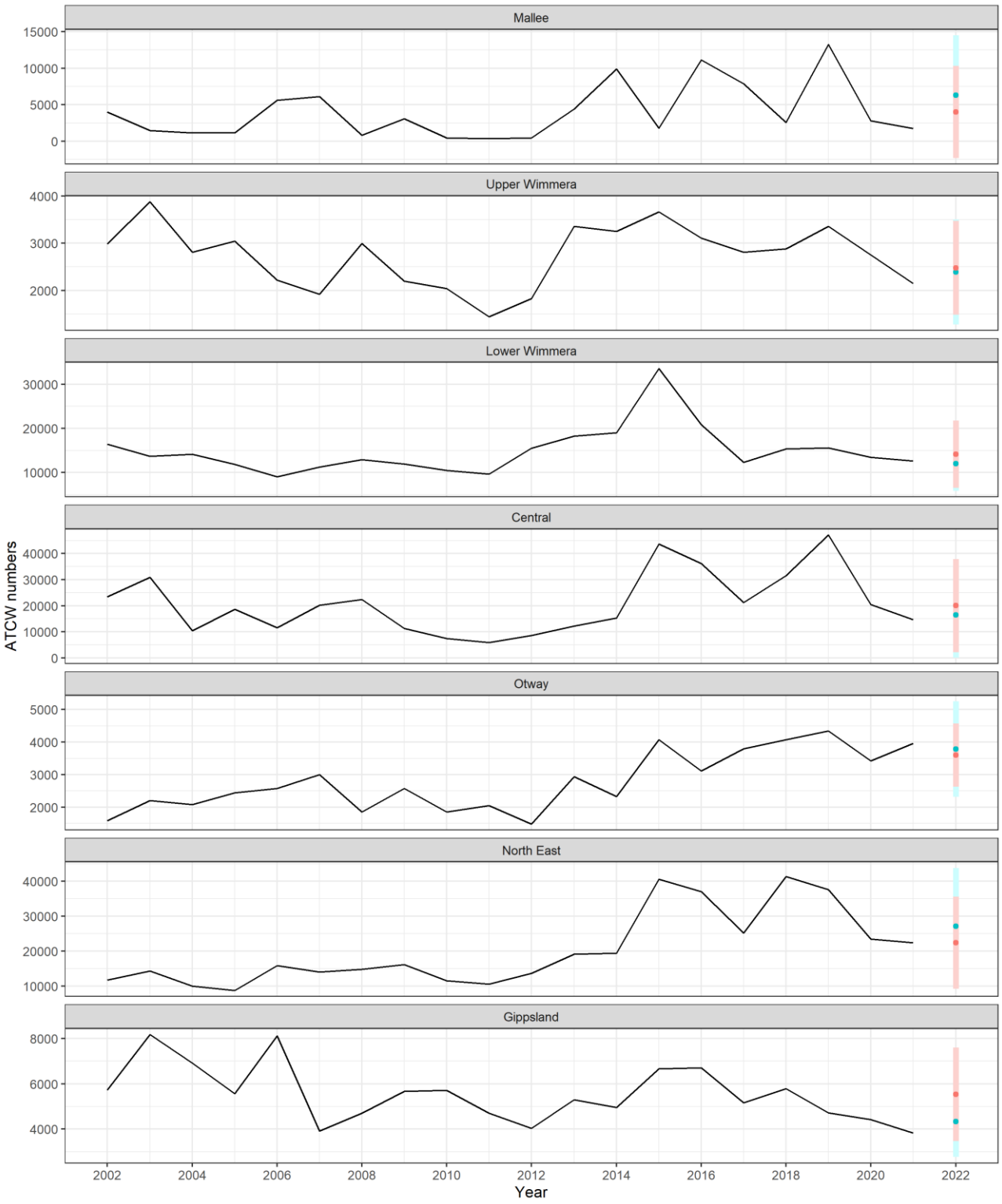

Figure 2. Time series of kangaroos taken under ATCW permits for each harvest zone from 2002 to 2021. The predicted ATCW numbers for 2022 (± 90% confidence interval) are that predicted by the ETS model (blue circle and shading) and the ARIMA model (red circle and shading).

Table 6. The total recommended take of grey kangaroos for 2022 compared with the predicted ATCW numbers from the model averaged estimates from the ETS and ARIMA time-series models. LCL, UCL – lower and upper 95% confidence intervals for the predicted ATCW. The ATCW (%) indicates the predicted ATCW numbers in 2022 as a percentage of the kangaroo abundance in the zone.

Zone	Total take	Predicted ATCW	LCL	UCL	ATCW (%)
Mallee	3,650	5,264	0	12,403	14.5
Upper Wimmera	13,350	2,435	1,382	3,487	1.8
Lower Wimmera	41,050	13,114	6,191	19,964	3.2
Central	65,050	18,330	1,190	35,194	2.8
Otway	23,600	3,687	2,472	4,912	1.6
North East	22,100	24,717	9,760	39,711	11.2
Gippsland	17,050	4,939	3,119	6,723	2.9
Total	**185,850**	**72,486**	**24,114**	**122,394**	**7.0**

3.3 Apportioning the quota between the KHP and ATCW permits

Based on the calculation of the total recommended take for grey kangaroos for each harvest zone (Table 3) and the expected demand for ATCW permits in each zone for 2022 (predicted ATCW: Table 6), the take 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 take 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 take (KHP + ATCW) did not exceed the total take for the state.

Table 7. Total recommended take of grey kangaroos, predicted ATCW numbers and recommended quotas for the KHP in 2022 by harvest zone. Values are rounded to the nearest 50.

Harvest Zone	Recommended take	Predicted ATCW	KHP quota
Mallee	3,650	5,250	0
Upper Wimmera	13,350	2,450	10,900
Lower Wimmera	41,050	13,100	27,950
Central	65,050	18,350	44,600
Otway	23,600	3,700	17,800
North East	22,100	24,700	0
Gippsland	17,050	4,950	12,100
Subtotals	**185,850**	**72,500**	**113,350**
Statewide Total			**185,850**

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. This approach was adopted in assigning the KHP quota for 2022.

Table 8. Alternative recommended quotas for the KHP in 2022 by harvest zone, assuming 20% of predicted ATCW control is undertaken through the KHP. Values are rounded to the nearest 50.

Harvest Zone	Recommended total take	Adjusted ATCW prediction	Adjusted KHP quota
Mallee	3,650	4,200	1,050
Upper Wimmera	13,350	1,950	11,400
Lower Wimmera	41,050	10,500	30,550
Central	65,050	14,700	46,150
Otway	23,600	2,950	20,650
North East	22,100	19,750	4,950
Gippsland	17,050	3,950	13,100
Subtotals	**185,850**	**58,000**	**127,850**
Statewide Total			**185,850**

4 Conclusions

Forecast abundances of grey kangaroos in each harvest zone at the end of 2021 were predicted to be similar to the estimates from aerial surveys in 2020. This is not surprising given the conservative settings for kangaroo maximum rate of increase r_m and carrying capacity K used in the model (Equation 1) and the fact that forecast total take was within sustainable limits. However, predicted estimates had a high uncertainty, which reflected the corresponding uncertainty in the key population parameters in the model. This situation is unlikely to change until sufficient aerial (and ground) survey information accumulate to enable direct estimates of these parameters from the monitoring data. We anticipate that a minimum of 8–10 aerial surveys will be required before parameter estimation from the monitoring data could be attempted. Given the uncertainty in key parameters currently used in the kangaroo harvest model, consideration could be given to setting quotas for years where no surveys are undertaken, based on the most recent aerial survey estimates and after adjusting for expected demand from ATCW permits. Hence, once an aerial survey is undertaken, quotas would be set for all subsequent years until the next aerial survey. Given an aerial survey frequency of 2–3 years, we anticipate that risk of over harvesting using this strategy would be slight, unless extreme environmental conditions for kangaroos are encountered (e.g. prolonged drought) or demand for ATCW permits exceeds expectations. Hence it would be prudent to combine this strategy with an annual review to assess whether modifications to the quota might be required, based on current environmental conditions.

Forecast total take for all zones, other than the North East, were predicted to be less than the nominal 10% recommended (Table 3). While the grey kangaroo take under the KHP was estimated to be slightly less than the recommended quota, considerably fewer kangaroos were taken under ATCW permit provisions than predicted by Ramsey and Scroggie (2020). It is possible that movement restrictions due to the COVID-19 health emergency may have reduced opportunities for kangaroo take under the ATCW provisions. As the current total take in each zone has not been excessive, and a wet year has been experienced across most of Victoria, significant declines in abundance within all harvest zones are unlikely. The results of aerial surveys planned for 2022 will be eagerly anticipated, as they will provide definite feedback on population trends under the current harvesting regime.

In most harvest zones, the number of grey kangaroos authorised to be taken under the ATCW permit process predicted for 2022 was lower than the number predicted for 2021. This lower forecast has in turn led to a corresponding increase in the quota available to be allocated to the KHP for most harvest zones, compared with 2021. The exceptions are the North East and Mallee harvest zones, where the ATCW permit numbers are forecast to be higher than the total recommended take. Accordingly, the quota allocated for the KHP in these zones was zero. However, assuming that 20% of the kangaroo control predicted under the ATCW system would instead be undertaken by commercial harvesters under the KHP as landholder awareness of the program increases, 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. While the overall 2022 KHP quota is higher than the 2021 quota, the total number of kangaroos that can be sustainably taken under both systems is lower than in 2021.

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 grey kangaroos. In addition, increased use of the KHP should lead to less wastage of carcasses, 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.

Recommendations

- For the 2022 calendar year, a total take of 185,850 grey kangaroos is recommended under the commercial harvest program (KHP) and ATCW permits. The total sustainable take of grey kangaroos in each harvest management zone, apportioned between the KHP and ATCW permit process, is shown in Table 7.
- Until sufficient aerial survey data accumulate to calibrate the kangaroo harvest model, consideration could be given to setting quotas for years where no surveys are undertaken based on the most recent aerial survey estimates, after adjusting for the projected uptake of ATCW permits. This should be

coupled with an annual review to assess whether modifications to the quota might be required, based on current environmental conditions.

- It would be desirable for the majority of grey kangaroos that would otherwise be taken 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 carcasses, improved animal welfare, and economic benefits for the state's commercial kangaroo harvesters.
- If a proportion of the predicted grey kangaroo taken 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.
- The number of grey kangaroos authorised to be taken through the ATCW permit process should be carefully monitored in both the Mallee and North East harvest zones. If demand exceeded expectations, the KHP quota would have to be adjusted to ensure the total take did not exceed the recommended sustainable take.
- 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.

References

Caughley, G., Brown, B., Dostine, P., and Grice, D. (1984). The grey kangaroo overlap zone. *Wildlife Research* **11**, 1–10.

Caughley, G., Shepherd, N., and Short, G. (1987). 'Kangaroos, their ecology and management in the sheep rangelands of Australia'. (Cambridge University Press: Cambridge.)

DELWP (2020). Victorian Kangaroo Harvest Management Plan. Department of Environment, Land, Water and Planning, Victorian Government, Melbourne. Available at: http://agriculture.vic.gov.au/__data/assets/pdf_file/0011/495029/Kangaroo-harvest-management-plan-2020.pdf?v=2

Hacker, R., Mcleod, S., Druhan, J., Tenhumberg, B., and Pradhan, U. (2004). Kangaroo management options in the Murray-Darling Basin. Murray-Darling Basin Commission, Canberra, Australia.

Holt, C. C. (2004). Forecasting seasonals and trends by exponentially weighted moving averages. *International Journal of Forecasting* **20**, 5–10.

Hyndman, R., and Athanasopoulos, G. (2019). 'Forecasting: principles and practice' 3rd ed. (OTexts: Melbourne, Australia.) Available at: https://otexts.com/fpp3/

McLeod, S. R., Hacker, R. B., and Druhan, J. P. (2004). Managing the commercial harvest of kangaroos in the Murray-Darling Basin. *Australian Mammalogy* **26**, 9–22.

Moloney, P. D., Ramsey, D. S. L., and Scroggie, M. P. (2017). A state-wide aerial survey of kangaroos in Victoria. Arthur Rylah Institute for Environmental Research Technical Report Series No. 286, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Moloney, P. D., Ramsey, D. S. L., and Scroggie, M. P. (2021). State-wide abundance of kangaroos in Victoria , 2020: Results from the 2020 aerial and ground survey. Arthur Rylah Institute for Environmental Research Technical Report No. 324. Department of Environment, Land, Water and Planning, Victoria.

Moloney, P. D., Scroggie, M. P., and Ramsey, D. S. L. (2018). Revisiting the Victorian kangaroo aerial survey design. Unpublished Client Report. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Ramsey, D. S. L., and Scroggie, M. P. (2020). Kangaroo harvest quotas for Victoria, 2021. Arthur Rylah Institute for Environmental Research Technical Report No. 323. Department of Environment, Land, Water and Planning.

Scroggie, M. P., Moloney, P. D., and Ramsey, D. S. L. (2017). Design of an aerial survey to estimate the abundance of kangaroos in Victoria. Arthur Rylah Institute for Environmental Research Technical Report No. 280. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Scroggie, M. P., and Ramsey, D. L. (2019). Kangaroo harvest quotas for Victoria, 2020. Arthur Rylah Institute for Environmental Research Technical Report Series No. 308. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Scroggie, M. P., and Ramsey, D. S. L. (2020). 'A Spatial Harvest Model for Kangaroo Populations in Victoria'. (Arthur Rylah Institute for Environmental Research Technical Report Series No. 315: Department of Environment, Land, Water and Planning, Heidelberg, Victoria.)

Scroggie, M. P., Moloney, P. D., and Ramsey, D. S. L. (2017). Design of an aerial survey to estimate the abundance of kangaroos in Victoria. Arthur Rylah Institute for Environmental Research Technical Report No. 280. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

www.delwp.vic.gov.au

www.ari.vic.gov.au