Abundance estimates for Stubble Quail in Victoria

Results from the 2024 survey

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

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Context:

Ensuring the sustainability of the impacts of hunting on the Victorian Stubble Quail (*Coturnix pectoralis*) population requires regular assessment of the abundance of this species across the state. In this way, changes in abundance can be monitored over time providing a clear basis for decision-making regarding the arrangements for legal hunting in the state. Earlier work (Scroggie and Ramsey 2023) has established a methodology for field surveys and estimation of total and regional abundances, and provides a basis for an updated population assessment for the year 2024.

Aims:

The aims of this study were to:

i. obtain updated estimates of total and regional abundance of Stubble Quail in Victoria for 2024, using the established survey methodology.

ii. compare the resulting estimates of abundance with those obtained from the previous (2023) survey.

iii. provide recommendations for any necessary improvements to the data collection and analysis procedures so that future surveys can continue to deliver precise and accurate estimates of Stubble Quail abundance.

Methods:

The line-transect distance sampling methodology used to obtain the 2023 population estimates was repeated during February 2024, with transects being surveyed at a total of 77 sites across Victoria. As most sites occur on private property, there were difficulties maintaining access to some of the sites surveyed previously. This necessitated the selection of new sites in some regions. We analysed the distance sampling data collected on the transects using both design-based and model-based approaches to yield estimates of abundance at both statewide and regional (Catchment Management Authority – CMA) scales.

Results:

Model-based analysis yielded a statewide abundance estimate of 5.4 million Stubble Quail (95% CI: 4.2–6.9 million). This was somewhat less than the previous, 2023 estimate of 6.6 million (95% CI: 5.1–8.7 million), although broad overlap in the confidence intervals for the two estimates means that the results do not unequivocally indicate a decline in abundance. Design-based estimates of abundance were generally similar to the model-based estimates.

The model-based estimation identified cover of crops, pasture and ecotonal areas where woody vegetation abuts crop, pasture and grassland as habitat covariates that were influential predictors of Stubble Quail abundance. High Stubble Quail densities were also associated with locations with intermediate crop cover, high pasture cover and low amounts of woody ecotone.

Conclusions and implications:

The survey methodology that was originally adopted in the 2023 report again yielded estimates of abundance with sufficient precision to support decision-making regarding the arrangements for hunting of Stubble Quail in Victoria. The statewide estimate of abundance was somewhat lower than that obtained during 2023, but is within the bounds of statistical uncertainty of the previous estimate. Much of Victoria experienced a relatively dry Spring and Summer during 2023/2024, which may have had some bearing on the population trend. However, the uncertainty around the abundance estimates and the small number of repeat surveys that have been conducted for Stubble Quail in Victoria precludes any strong conclusions regarding the environmental or management drivers of temporal changes in abundance.

Recommendations:

- We recommend that the survey is repeated annually using the current methodology. This will allow ongoing monitoring of trends in abundance and regular re-assessment of the ecological sustainability of hunting arrangements for Stubble Quail.

- If possible, additional sites could be added to the survey program to improve the precision of the regional (CMA) abundance estimates. This would be of greatest value in under-sampled parts of the state, such as the East Gippsland and North East catchments. Further data from under-sampled parts of the state will both improve the precision of the population estimates and reduce the extent to which they rely on extrapolation in geographic and environmental space.
- After two more annual surveys have been conducted, consideration could be given to applying a spatiotemporal model of abundance. This approach infers the pattern of variation in abundance in both space and time. Such an approach is likely to result in improved precision, as well as provide understanding of temporal trends in abundance and how they vary across the state.
- Once 5 years of survey data have been accumulated, consideration could be given to developing a sustainable harvest model for Stubble Quail in Victoria, which includes the impact of hunting. Such a model could be used to assist with decision-making regarding hunting arrangements, and would increase the transparency of the regulatory process.

1 Introduction

Hunting of native Stubble Quail *(Coturnix pectoralis)* by licenced hunters occurs in Victoria during an annual hunting season. Season dates, daily bag limits and hunting methods are prescribed in the Wildlife (Game) Interim Regulations 2023. These arrangements are made for the purpose of ensuring the ecological sustainability of Stubble Quail hunting. The numbers of Stubble Quail taken by samples of hunters during each season are determined via a regular telephone survey of hunters, with the total number of birds harvested being derived from these surveys by extrapolation to the total number of active licenced hunters in the state (Moloney and Flesch 2023a).

While the total harvest (as determined by the telephone surveys) provides important information for determining the hunting arrangements, a proper assessment of the sustainability of the hunt requires estimates of the total, and ideally regional Stubble Quail population of the state. Such estimates provide understanding of the likely proportion of Stubble Quail that are harvested in a given year, which is a key piece of information for assessing the likely population-level impacts and sustainability of Stubble Quail hunting.

Recently, ARI has been engaged by the Game Management Authority to develop and implement a survey and monitoring program for the Victorian Stubble Quail population. Initial work using line-transect distance sampling (Buckland et al. 1993) conducted during 2022, identified the need for modifications to the initial field methodology to improve detection of birds (Scroggie and Ramsey 2022). During 2023, further statewide surveys with the modified survey methodology led to improved detection of birds and allowed more precise estimation of the number of Stubble Quail in the state at both regional and statewide scales (Scroggie and Ramsey 2023). This work largely solved the methodological problems encountered during the initial survey, and the modified methodology is now considered fit-for-purpose for future surveys.

During February 2024, an additional statewide survey was conducted to provide an updated assessment of the abundance of the Stubble Quail using the modified survey methods. This report describes the results of the 2024 survey, and provides the associated population estimates that will be used to provide advice to the minister with regards to the arrangements for the 2024 Stubble Quail hunting season.

1.1 Objectives

The aims of the current study were to (1) use the established survey methodology to obtain updated estimates of total and regional abundance of Stubble Quail in Victoria for 2024, (2) compare the resulting estimates of abundance with those obtained from the previous (2023) survey, and (3) provide recommendations for any necessary improvements to the data collection and analysis procedures so that future surveys can continue to deliver precise and accurate estimates of Stubble Quail abundance.

2 Methods

2.1 Monitoring sites

A total of 77 sites were included in the current survey. The predominant land uses at the sites were non-native pasture, dryland cropping (stubble) and native grassland. Selection of sites was based on a stratified random sampling design, with strata consisting of the catchment management authority (CMA) regions as well as the three land uses. Note, that as of February 2021, the former Port Phillip and Westernport CMA was merged with Melbourne Water. For consistency with legacy spatial data that are used in our analysis, we have retained the previous name for this CMA throughout the report. Land use mapping data was that of White et al. (2020) and has been described in our previous (2023) report.

While a proportion of the Victorian Stubble Quail population may occupy other habitat types, such as seasonal wetlands, the three land uses that were targeted in our surveys represent the majority of preferred habitat, and are the habitats in which hunting is most likely to occur. For these reasons, we consider that this approach to survey site selection is appropriate for the intended management use of the resulting population estimates, but stress that it will likely represent an underestimate of the total population.

Difficulties with obtaining sufficient sites with appropriate land use type in each CMA meant that the survey data are somewhat unbalanced with respect to the overall availability of habitat within each CMA. Furthermore, only a small number of sites were able to be surveyed in certain catchments. The locations of survey sites and mapped habitat types are displayed in Figure 1. The numbers of sites that were located in each CMA and in each land use category (based on mapped land use at the site centroid) are given in Tables 1a,b.

Each site consisted of multiple transects that were typically 1 km in length. Transects at the same site were positioned in parallel with a spacing of at least 200 m between adjacent transects to avoid issues with birds being flushed from one transect to another and double counted. The distance of 200 m was chosen by examining distances moved by flushed quail during an initial pilot survey. It was intended that a total of 4 km of transect effort be expended at each site. However, logistic, safety or access constraints sometimes resulted in less than 4 km of total effort at certain sites. The actual transect lengths were recorded using a portable GPS device, and this information was incorporated into the statistical modelling process to account for the actual survey effort that was applied at each site. The mean total length of transects across all 77 sites was 3.18 km.

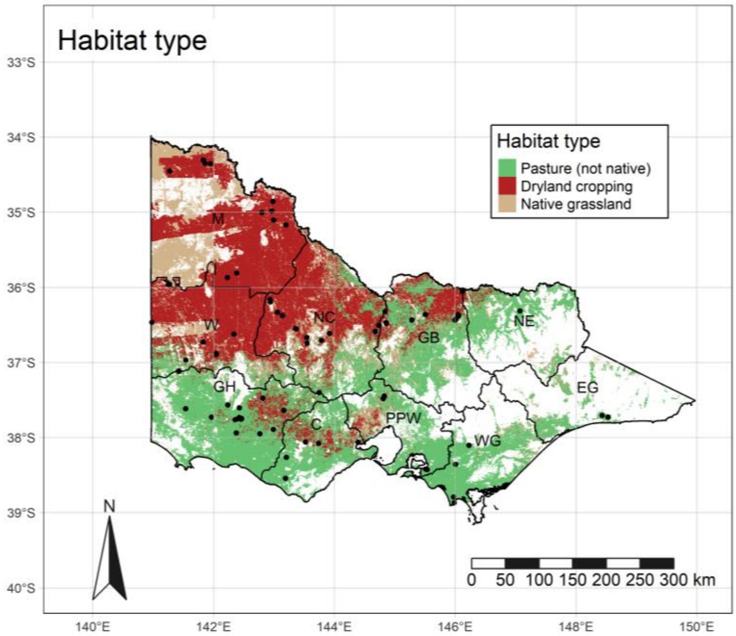

Figure 1. Map showing broad land use categories and locations of survey sites within Victoria

Map shading illustrates broad land use categories within the state, as well as the boundaries of Catchment Management Authority regions (black internal boundaries) and the locations of the survey sites for the 2024 Stubble Quail survey (black points).

Table 1a. Number of sites within each Catchment Management Authority (CMA) area and each broad land use category

Tabulation of habitat types is based on mapped land use at the site centroid.

CMA	Number of sites
Corangamite	5
East Gippsland	2
Glenelg Hopkins	14
Goulburn Broken	12
Mallee	11
North Central	15
North East	1
Port Phillip and Westernport	4
West Gippsland	4
Wimmera	9
TOTAL	**77**

Table 1b. Number of sites within each mapped land use category at the site centroid.

Land use category	Number of sites
Dryland crops	36
Native grassland	6
Non-native pasture	35
TOTAL	**77**

2.2 Survey methods

As was the case during the 2023 surveys, Stubble Quail density at the survey sites was estimated from the field data using line-transect distance sampling methods (Buckland et al. 1993). The field methodology used for the 2024 surveys was identical to that used during 2023. Briefly, line transects were walked with three observers line-abreast, with the two outer observers walking 10 m either side of the central observer. A 20 m length of rope was spread between and held by all three observers, and dragged along the ground to assist with flushing birds. Stubble Quail that were flushed were counted (including birds beyond the two outer observers out to a maximum of 20 m from the transect line), and the distance from the centre line at the point of first detection was measured. More details of the survey methods can be found in the 2023 report (Scroggie and Ramsey 2023).

2.3 Estimating Stubble Quail abundance

2.3.1 Distance sampling

A two-stage modelling process was adopted for analysing the data. Firstly, a detection function was fitted to the distance data to estimate the effective detection distance of groups of birds located in the vicinity of the transect line (the transect half-width). The fitted distance function provides a basis for statistical estimation of the proportion of Stubble Quail groups that were detected and counted by the observers out to the maximum (20 m) truncation distance either side of the transect lines. We considered several alternative distance models for the data including hazard rate, half normal and uniform functions with and without cosine, polynomial and Hermite adjustment terms (Buckland et al. 1993). Adjustment terms were progressively added to the basic (key function only) models until there was no improvement in Akaike's Information Criterion (AIC, Burnham and Anderson 2002). We also considered models with and without a group size effect, because it was considered likely that larger groups of Stubble Quail might have been easier to detect. While selection of a final, preferred distance model was mainly guided by AIC values, we also evaluated the goodness of fit using Chi-squared tests, and compared models with different approaches to binning of the distance data into discrete distance bands. This latter approach is helpful where distinct ‘spikes’ occur in the histogram of detection distances as a result of either unintentional rounding of distances by the observers or repulsive movement of animals away from the observers (Buckland et al. 1993).

2.3.2 Design-based estimates of abundance

As was the case for the 2023 surveys, we have generally favoured a model-based approach (Miller et al. 2013; Buckland et al. 2016) to the analysis and interpretation of the Stubble Quail data, because it allows the estimation process to benefit from inferred relationships between local abundance and mapped habitat covariates. This approach also allows estimation of abundance at scales smaller than the survey stratum, yielding mapped estimates of density across the study area. In contrast, design-based approaches do not rely on inferred statistical relationships with habitat covariates and therefore, make fewer ecological or statistical assumptions. They therefore can provide a useful check of the plausibility of the model-based inference approaches.

Our design-based estimates are based on stratification of land use types only, because a lack of replication (i.e. a small number of survey sites) in some CMA areas precluded the computation of design-based estimates for every catchment. For the purpose of this analysis, transects were assigned to one of the three major land use categories on the basis of the land use at the centroid of each site. Following estimation of the preferred distance function (see section 2.3.1), the mean and standard error of Stubble Quail density on transects of each land use type was computed and standard Horvitz-Thompson approaches (Buckland et al. 1993) were used to extrapolate these results to the full extent of each habitat type across each CMA. This approach yields design-based estimates of the total population of Stubble Quail (with associated coefficients of variation and 95% confidence intervals) for the statewide extent of each of the three major land use categories.

2.3.3 Model-based estimates of abundance

Model-based estimation of abundance followed the same process as was used in the 2023 report. We used density-surface models (DSMs, Miller et al. 2013; Buckland et al. 2016) to relate the densities of Stubble Quail observed on the transects to a series of spatially-referenced covariates. This allowed us to establish a statistical relationship between habitat variables and Stubble Quail density, which could then be extrapolated to the entire study area. The resulting model allows prediction of density at any location in the study area as well as estimation of the total population, or the population in any subset of the study area (in this case the CMA regions) by summing the predicted abundances within grid cells of the area of interest to obtain an abundance estimate.

The DSMs allowed for non-linear relationships between abundance and habitat variables using generalised additive models (GAMs, Wood 2017). Selection of variables for inclusion in the model was done by eliminating uninfluential variables until there was no further improvement in AIC. We fitted the DSMs using the R package *dsm* (Miller et al. 2020), which provides a wrapper for incorporating distance sampling data into the facilities for the fitting of GAMs provided by the R package *mgcv* (Wood 2017).

2.3.4 Spatial modelling

The habitat covariates included in the spatial model were the same as those used in the 2023 report unless otherwise stated. Full details can be found in Scroggie and Ramsey (2023). Maps showing spatial variation in the habitat variables are given in the Appendix to this report. The variables used in the model were:

- Landcover data: proportions of crop, pasture, grassland, woody vegetation within each 1 km grid cell.
- Ecotonal habitat: number of 25 m sub-cells containing edges of woody vegetation within each 1 km grid cell.
- NDVI (normalised difference vegetation index, Pettorelli et al. 2005): a remote sensed dataset (MODIS, Didan 2015) was obtained from Google Earth Engine (Gorelick et al. 2017) and used to determine vegetation greenness across the entire study area during January 2024, a period that coincides with the time at which the Stubble Quail surveys were conducted.

The latitude and longitude of each survey location was also treated as a predictor of abundance to detect any large-scale spatial trends in abundance that were not well explained by the habitat covariates.

Initially, five models were considered:

1. A null model with no covariates (i.e. constant Stubble Quail density across all habitats).

2. A spatial trend model that included only latitude and longitude covariates, specified as a bivariate thin-plate spline (Wood 2003).
3. A model that included only vegetation greenness (NDVI). The relationship between Stubble Quail density and NDVI was modelled using a thin plate spline term.
4. A model with both habitat (proportional land use) and NDVI covariates, all specified as thin plate splines. Initial fits included all land use categories and NDVI, with uninfluential variables being progressively eliminated until no further reduction in AIC was noted.
5. As above, but with a bivariate spatial spline also included in the model to account for spatial variation in Stubble Quail density that was not explained by the habitat covariates.

We compared the performance of versions of the candidate models with Poisson, Negative Binomial and Tweedie error distributions. Alternative models were compared using AIC with the intention of maximising model parsimony and therefore predictive performance (Burnham and Anderson 2002).

The preferred spatial model was used to predict variation in the density of Stubble Quail across suitable habitat for the entire state, and to infer the total abundance for the state and for each CMA region.

3 Results

3.1 Survey results

A total of 246 detections of Stubble Quail groups (including a group size of 1) were included in the analysis after removing some very long-distance detections by truncating the maximum detection distance at 20 m. The mean group size was 1.3 birds, with only seven groups of more than three birds being observed.

3.1.1 Analysis of distance-detection data

The various distance functions were fitted to the data and compared based on AIC. For each distance function, the average probability of quail detection ($\hat{p}$) (out to the right truncation distance of 20 m) was derived using numerical integration. Binning of the detection data proved necessary to account for an apparent spike in the distance data close to the transect line. The hazard-rate model with Hermite adjustment terms failed to converge, so was excluded from further consideration. Comparison of fitted models led to selection of a simple hazard rate without adjustment terms or a group size covariate. Although model selection uncertainty was high (several models had AIC within 2 units of the best model, Table 2), all of the top five models implied a $\hat{p}$ value in a very narrow range (0.47–0.53), so the effects of model selection uncertainty on the implied probability of detecting groups of Stubble Quail were minimal. Checking of the predictions of the preferred model against the observed data using a Chi-squared test showed no significant goodness-of-fit issues (χ^2= 3.669, df=4, p=0.453).

The preferred model (hazard rate) was the same as that identified as the preferred model during the 2023 survey (Scroggie and Ramsey 2023), and the resulting estimate of $\hat{p}$ (0.53), was also very similar to the estimate reported in the 2023 study ($\hat{p}$ = 0.56).

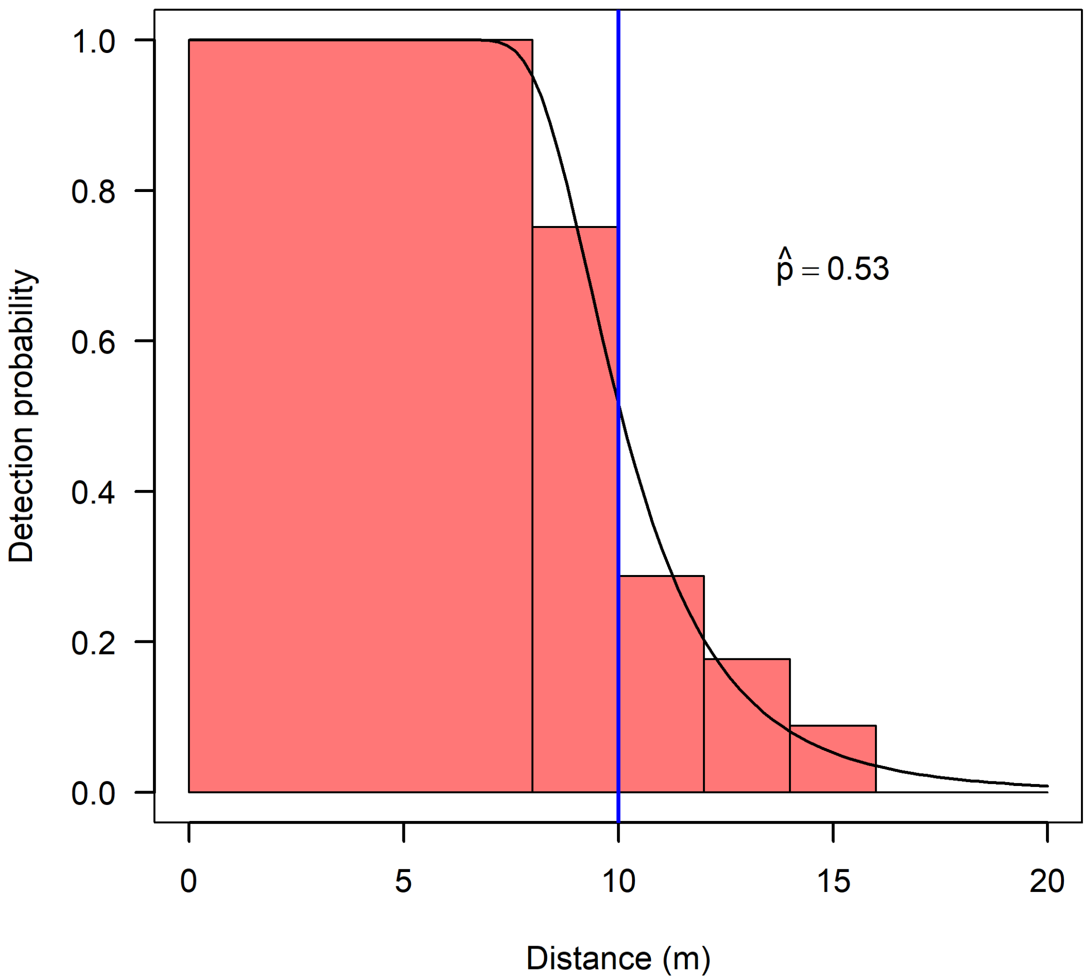

Figure 2. Fitted distance function (hazard rate)

The vertical blue line indicates the distance from the transect line at which the outer observers were positioned while surveying the transect. The black line is the fitted hazard rate function. $\hat{p}$ is the estimated proportion of Stubble Quail groups detected out to the right truncation distance of 20 m.

Table 2. Summary statistics for the distance-detection models

A smaller AIC indicates a more parsimonious model with better expected predictive performance. $\hat{p}$ is the area under the fitted distance function out to the right-truncation distance of 20 m and gives the probability of detecting each quail group actually present within the 20 m strip either side of the central observer. The effective transect half-width is the equivalent transect half-width (m) for a hypothetical transect survey that detects all groups actually present. Key = key function, Adjustment = adjustment series, df = degrees of freedom, AIC = Akaike information criterion; ΔAIC = the difference between the AIC of the model and the AIC of the model with minimum AIC.

Key function	Adjustment	Covariate	df	AIC	ΔAIC	$\hat{p}$	Effective half-width
Hazard rate	-		2	407.1154	0	0.53	10.61
Hazard rate	-	Size	3	407.2747	0.159	0.53	10.58
Half-normal	Hermite		2	407.5813	0.466	0.47	9.34
Hazard rate	Polynomial		3	407.8128	0.697	0.52	10.49
Half-normal	Cosine		3	407.8682	0.753	0.51	10.21
Hazard rate	Cosine		3	409.1267	2.011	0.53	10.60
Half-normal	Polynomial		2	409.7098	2.594	0.42	8.30
Half-normal	-		1	410.7669	3.652	0.40	7.99
Half-normal	-	Size	2	411.0325	3.917	0.40	7.93
Uniform	Cosine		1	415.3419	8.226	0.50	10.00
Uniform	Polynomial		3	419.6984	12.583	0.52	10.33
Uniform	Hermite		2	457.5712	50.456	0.62	12.44

3.2 Abundance estimates

3.2.1 Design-based estimates of abundance

The design-based estimates of abundance for each of the three land use categories are given in Table 3. The abundance estimates range between 0.7 million for the native grassland stratum and 3.4 million for the dryland crop stratum. The design-based estimate of abundance for the entire study area was 5.7 million. Precision (as expressed by the coefficient of variation, CV) for the design-based estimate of the total population was quite good at 0.18, as were the CVs for the dryland crop and non-native pasture strata, which were both less than 0.3. The relative precision of the estimate for native grassland (CV=0.5) was rather poor, due to the small number of native grassland sites surveyed. However, this is of little consequence for the statewide estimate given the relatively small proportion (~16%) of the study area that was comprised of this land use type (Table 3). Density of Stubble Quail was highest in dryland crops and lowest in non-native pasture, although there was considerable overlap between the confidence intervals of the density estimates.

Table 3. Design-based estimates of abundance of Stubble Quail in Victoria

Estimated abundance, ($\hat{N}$, rounded to the nearest thousand) and density (individuals per km2) for Stubble Quail based on stratification of the survey sites into three major habitat types. Figures in parentheses are the 95% confidence intervals for the abundance and density estimates. CV = coefficient of variation (applies to both density and abundance).

Stratum	Area (km^2)	Effort (km)	Abundance ($\hat{N}$)	Density (Quail per km^2)	CV
Dryland crops	52,831	107.4	3,431,000 (2,022,000 – 5,823,000)	64.9 (38.3 - 110.2)	0.27
Native grassland	20,046	20.3	698,000 (206,000 – 2,364,000)	34.8 (10.3 – 118.0)	0.50
Non-native pasture	50,781	117.4	1,570,000 (1,033,000 – 2,386,000)	30.9 (20.3 - 47.0)	0.21
TOTAL	123,658	245.2	5,699,000 (3,960,000 – 8,201,000)	46.1 (32.0 - 66.3)	0.18

3.2.2 Model-based estimates of abundance

Density surface models with Tweedie error distribution were overwhelmingly superior to those with Poisson or Negative Binomial errors, accordingly, only the Tweedie models are presented here. While the model including habitat covariates, but no spatial smoothing term had a marginally superior AIC to the equivalent model with spatial smoothing terms included, we preferred the latter more complex model because it explained a higher proportion of total deviance (45% versus 39%) (Table 4). We also considered this model preferable because our inferences regarding total abundance rely strongly on both spatial and environmental extrapolation. Inclusion of a spatial smoother captures additional information regarding spatial trends in abundance that are not adequately explained by the habitat covariates. This model therefore provides some protection against inappropriate extrapolation in space based purely on observed habitat-abundance relationships.

Table 4. Summary statistics for the set of candidate spatial models

These are density surface models (DSMs) for the density of Stubble Quail across Victoria. All models used the Tweedie error distribution for their responses. The notation s(x) indicates a smooth relationship (in this case described by a thin-plate spline, see methods). Models are ordered in decreasing order of parsimony, based on their AIC values. edf – effective degrees of freedom, AIC – Akaike's information criterion, ΔAIC – AIC – min(AIC).

Model	edf	AIC	ΔAIC	% Deviance explained
s(crop)+s(pasture)+s(wood_edge)	7.5	343.2	0	39
s(lat, long)+s(crop)+s(pasture)+s(wood_edge)	11.6	344.1	0.9	45
s(lat, long)	6.8	373.7	30.5	11
s(ndvi)	3.9	375.6	32.4	2
Null model (intercept only).	3.0	376.1	32.9	0

The fitted curves for the habitat-abundance relationships within the preferred DSM (Figure 3) showed an association between high Stubble Quail densities and moderate to high levels of cropping land use, high levels of pasture land use, and low amounts of ecotonal habitat around the edges of woody habitat. Fitted relationships for pasture cover and amount of woody edge habitat were essentially linear, while the relationship with amount of crop habitat suggested that Stubble Quail densities were likely to be highest when crop cover was between approximately 50 and 80%.

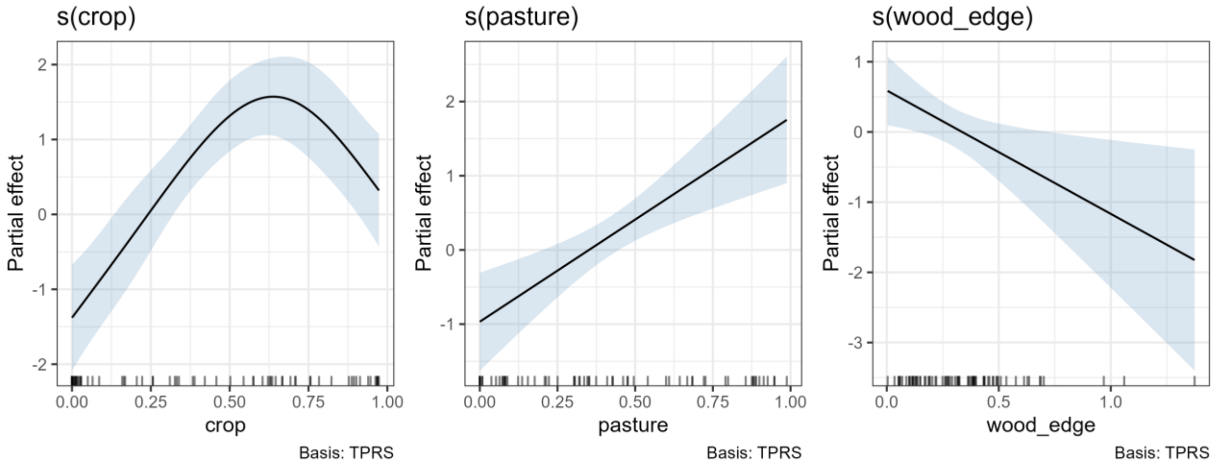

Figure 3. Effects of covariates on the log-density of Stubble Quail in the study area

These are thin-plate spline terms representing the partial effect of each covariate on the log-abundance of Stubble Quail on the survey transects.

Interestingly, the fitted partial effects of the covariates differed somewhat from those noted in the analysis of the 2023 survey. In 2023, Scroggie and Ramsey (2023, Figure 5) noted generally similar effects of crop and wood edge amount on the log-abundance of Stubble Quail. However, the more or less positive linear effect of pasture cover on log-abundance of Stubble Quail seen in 2024 (Figure 3) was reversed from that seen in 2023, where a non-linear, decreasing partial effect of pasture cover was noted.

The spatial smoothing effect (bivariate thin-plate spline on latitude and longitude) of the preferred model revealed that the Stubble Quail were at higher densities than would be expected purely on the basis of the fitted habitat-abundance relationships across much of central, western and north-western Victoria (Figure 4 – tan colouring). In contrast, densities were lower than expected on the northern plains, in East Gippsland and in the far south-west of the state (Figure 4 – blue colouring).

Prediction of Stubble Quail density at each 1 km grid cell allowed estimation of the total Stubble Quail abundance for each CMA, as well as the statewide total (Table 5). The largest population was found in the North Central CMA, which was estimated to contain over one million Stubble Quail. In contrast, the population of Stubble Quail in the East Gippsland CMA was estimated at only 35 thousand (Table 5). The statewide estimate of Stubble Quail abundance was 5.4 million.

Relative precision of the population estimates for the catchments (expressed as the coefficient of variation, CV) were generally less than 0.3, with the exception of the West Gippsland and East Gippsland catchments. Both of these catchments had relatively small numbers of survey sites, meaning that estimation of abundances for these catchments was largely driven by extrapolation. The CV of the overall, statewide estimate of abundance was 0.13, which indicates a very good level of precision.

The model-based estimate of the total population (5.4 million, 95% CI 4.2–6.9 million, CV=0.13) was broadly comparable to the design-based estimate of 5.7 million (95% CI 4.0–8.2, CV=0.18). The narrower confidence limits and smaller CV of the model-based estimate both indicate more precise estimates when using the model-based approach.

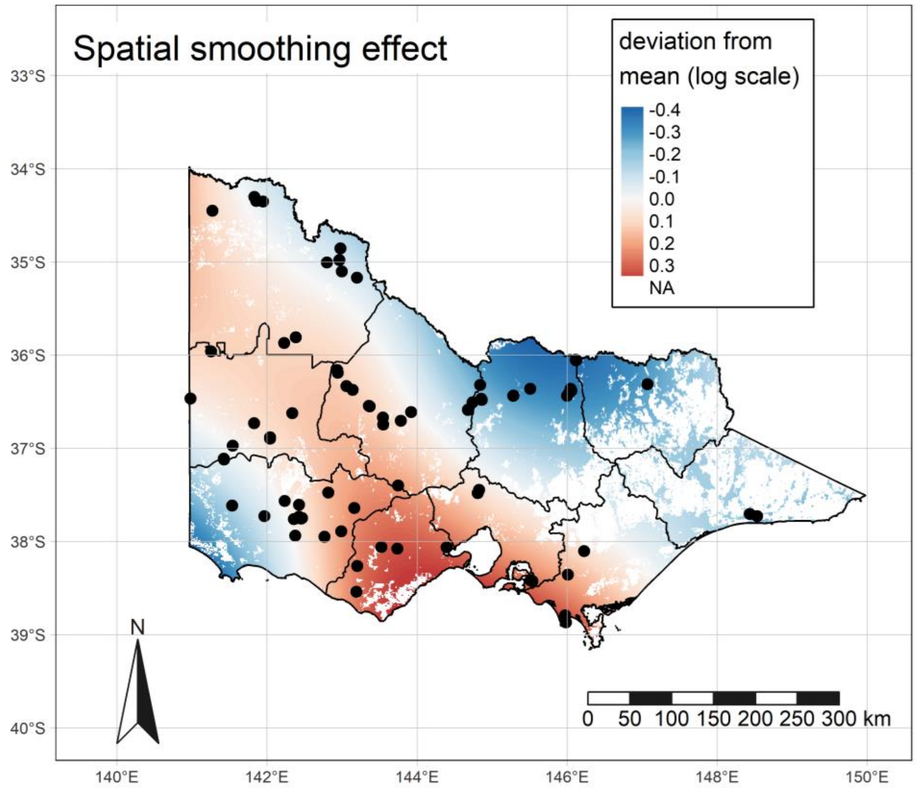

Figure 4. Spatial smoothing effect from the preferred model for the abundance of Stubble Quail indicating where densities were higher (tan colouring) or lower (blue colouring) than expected

The mapped quantity represents the component of spatial variation in abundance that is not explained by the habitat covariates of the density surface model. NA – no applicable habitat; black dots denote the locations of the study sites.

Table 5 . Model-based estimates of abundance of Stubble Quail in CMA regions in Victoria

Abundance, ($\hat{N}$, rounded to the nearest thousand) for Stubble Quail based on stratification of the survey sites into three major habitat types. CV = coefficient of variation. Area of habitat totals include only the areas within each CMA that are mapped as dryland crops, native grasslands and pastures.

CMA	Area (km^2)	Sites	Abundance ($\hat{N}$)	Lower 95% bound	Upper 95% bound	CV
Corangamite	8,375	5	706,000	465,000	1,070,000	0.21
East Gippsland	1,980	2	35,000	19,000	63,000	0.31
Glenelg Hopkins	16,825	14	946,000	674,000	1,328,000	0.17
Goulburn Broken	12,895	12	377,000	243,000	586,000	0.23
Mallee	25,976	11	816,000	511,000	1,302,000	0.24
North Central	22,476	15	1,073,000	735,000	1,565,000	0.19
North East	5,468	1	107,000	64,000	179,000	0.27
Port Philip and Westernport	5,781	4	245,000	143,000	421,000	0.28
West Gippsland	6,142	4	292,000	155,000	550,000	0.33
Wimmera	17,740	9	769,000	487,000	1,215,000	0.24
TOTAL	123,658	77	5,366,000	4,159,000	6,925,000	0.13

3.2.3 Spatial variation in Stubble Quail density

The density surface model allows prediction of the density of Stubble Quail within suitable habitat across the entirety of the study area, along with associated measures of uncertainty (i.e. the coefficient of variation, CV). The spatial predictions allow identification of areas of especially high and low expected density (Figure 5). Especially high densities of Stubble Quail were predicted to occur on the plains of south-western Victoria, (within parts of the Corangamite and Glenelg Hopkins CMA) and in the southeast of the state near the boundary of the Port Philip and West Gippsland catchments. In contrast, predicted densities on the northern slopes of the Great Dividing Range and on more easterly parts of Gippsland were predicted to be rather low (Figure 5).

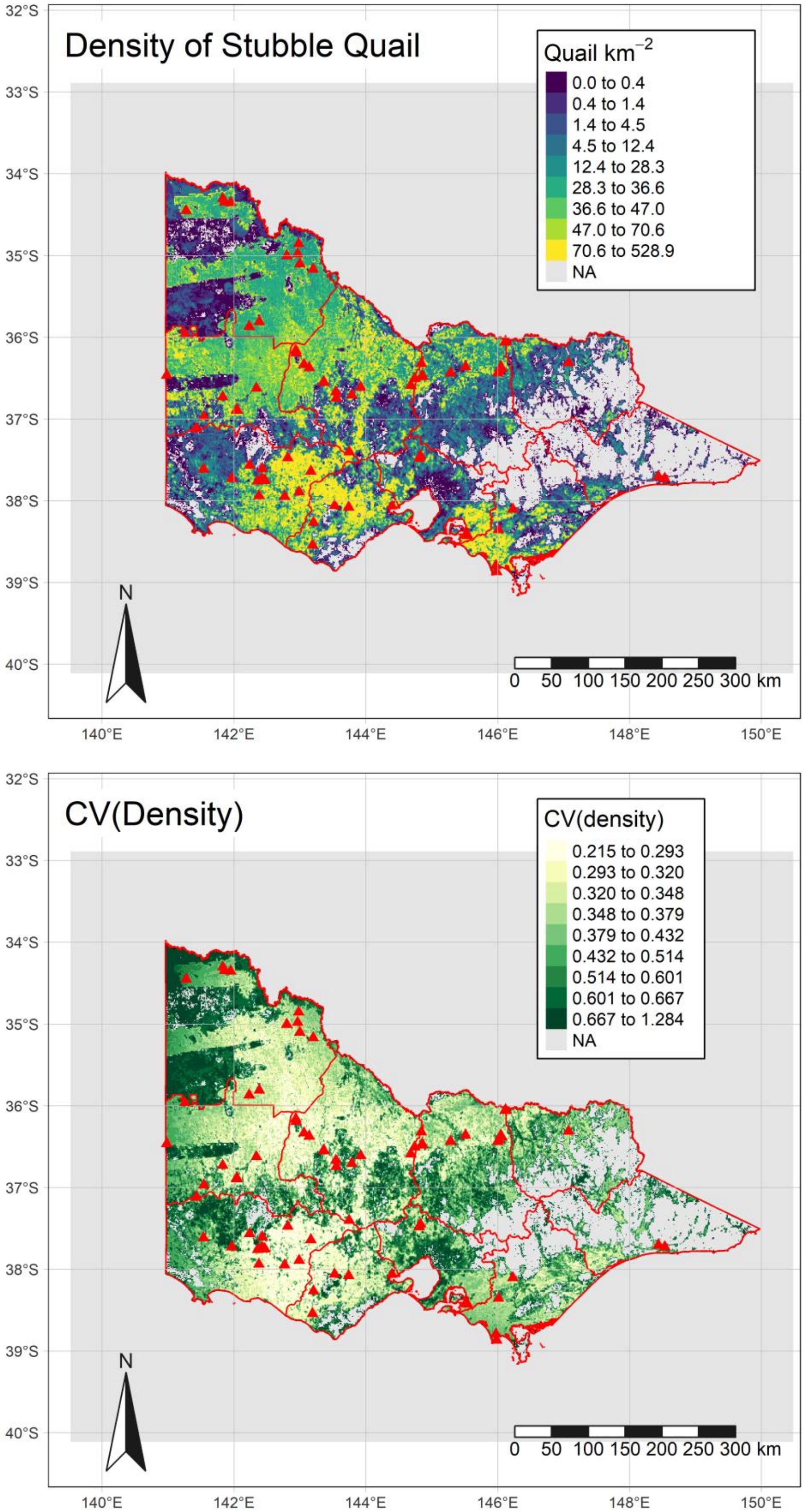

Figure 5. Spatial variation in the density of Stubble Quail during January 2024

The upper panel represents the predicted density of Stubble Quail within suitable habitat (crops, grasslands, pastures) across the study area. It is important to note that not every grid cell (1 km x 1 km) within the prediction domain of the model consists entirely of suitable habitat (crop, grassland, pasture), so the inferences are of density within the portion of each grid cell that consists of these habitat types, however small that may be. Overlaid red internal boundaries are the CMA areas. The lower panel represents relative uncertainty in the density estimates, expressed as the coefficient of variation (CV).

3.2.4 Temporal trends in Stubble Quail abundance

The predicted statewide total abundance of Stubble Quail for 2024 (5.4 million) was approximately 20% less than the equivalent prediction from the 2023 survey (6.7 million, Scroggie and Ramsey 2023). However, the point estimate for 2024 was within the bounds of statistical uncertainty for the 2023 estimate, meaning that the results do not convey statistical certainty as to whether a decline has actually occurred (Figure 6).

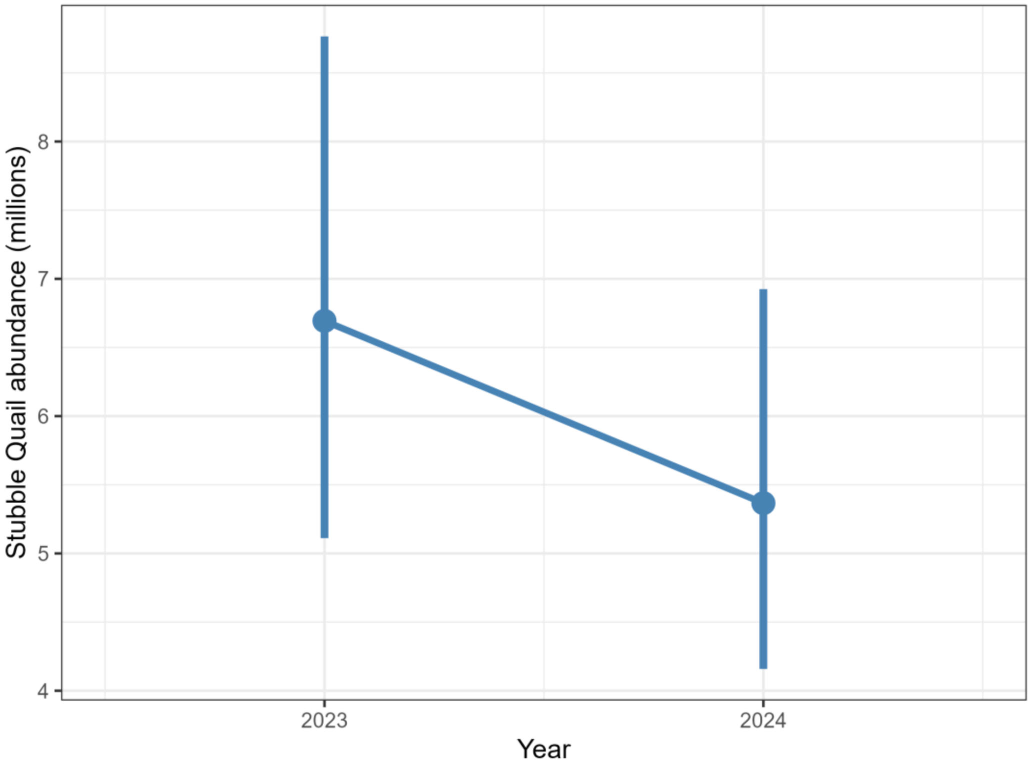

Figure 6. Model-based estimates of statewide Stubble Quail abundance for the years 2023 and 2024

Error bars are the 95% confidence limits of the estimates. The 2023 results are derived from the study of Scroggie and Ramsey (2023).

There were a range of increases and declines observed when considering the abundance estimates at a regional (CMA) level (Figure 7). Many of the observed changes were within the confidence bounds of the 2023 estimates, in line with the statewide results (Figure 6). The most notable changes included an apparent large increase in abundance within the Corangamite CMA, where the estimated number of Stubble Quail more than doubled from 298 thousand during 2023 to over 700 thousand in 2024. In contrast, the estimated abundance in the Wimmera CMA nearly halved from over 1.3 million in 2023 to 769 thousand in 2024. In most other catchments, the observed changes in abundance were within the bounds of statistical uncertainty (Figure 7).

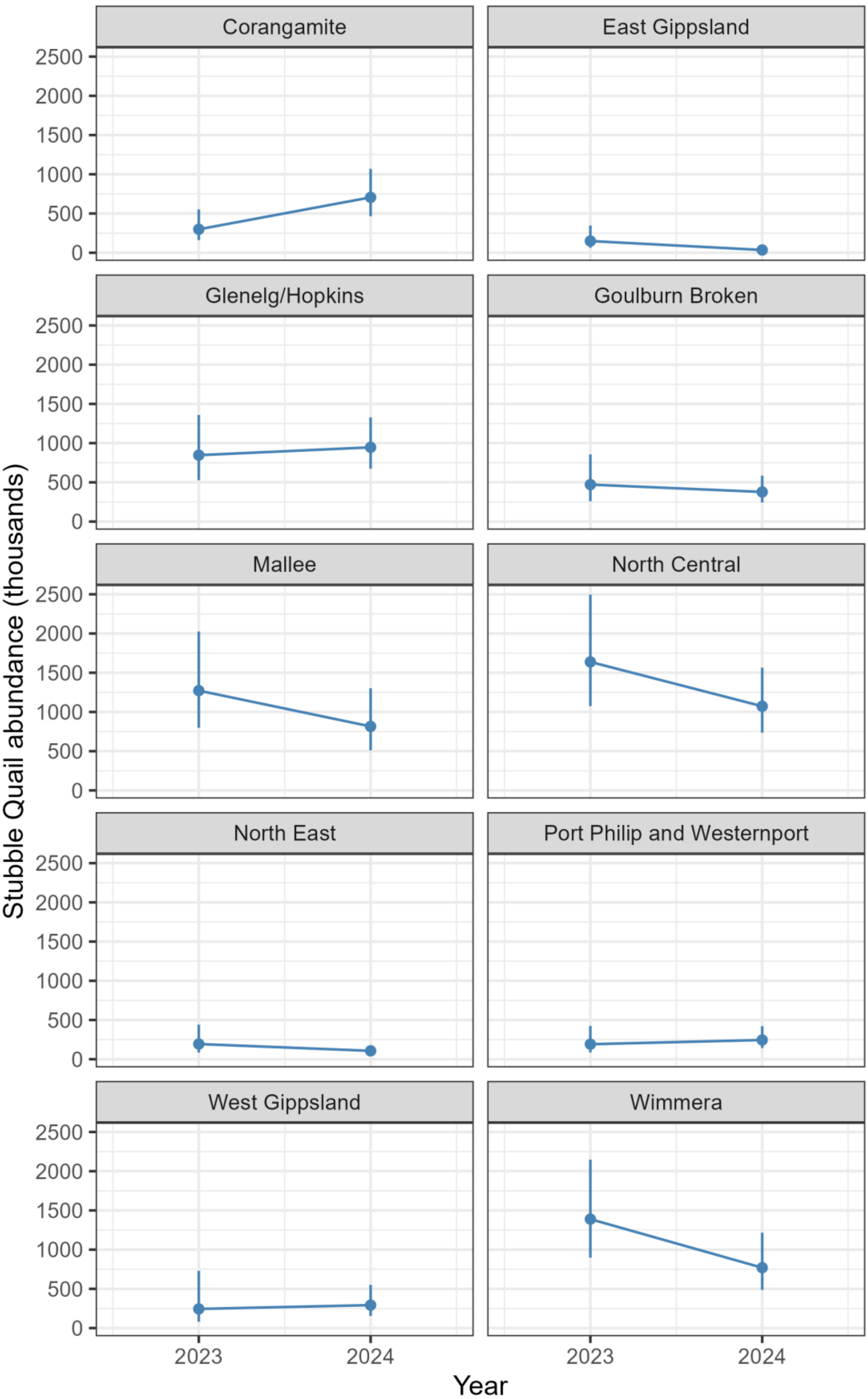

Figure 7. Model-based estimates of total Stubble Quail abundance (in thousands) for each Victorian Catchment Management Authority (CMA) area for the years 2023 and 2024

Error bars are the 95% confidence limits of the estimates. The 2023 results are derived from the study of Scroggie and Ramsey (2023).

4 Discussion

The results of the 2024 Victorian Stubble Quail survey presented here confirm that the existing methodology for assessing population abundance has continued to work well. The survey and associated analysis yielded precise estimates of Stubble Quail abundance at both the regional (CMA) and statwide scales. Higher uncertainty in certain catchments (East Gippsland, West Gippsland, North East) occurs largely as a consequence of the small number of sites surveyed in these areas, meaning that inferences regarding Stubble Quail abundance in those areas flow largely from the limited data and reliance on extrapolation to obtain population estimates. If more precise estimates are desired from these CMAs, then surveying additional sites should yield the desired improvements in precision. In a similar vein, the relatively low precision of Stubble Quail density estimates in native grassland habitat was also a consequence of the small number of native grassland sites surveyed. However, due to the relatively small proportion of native grassland habitat across the state (~16%), the low precision had relatively little impact on the uncertainty in the total design-based estimate of quail abundance.

The results provide an updated picture of the status of the Victorian Stubble Quail population. An apparent 20% decline in abundance since the previous, 2023 report (Scroggie and Ramsey 2023) is noted. However, the statistical uncertainty in the two successive statewide population estimates means that this result needs to be interpreted cautiously. While a 20% decline is the most likely interpretation, the result is also consistent with smaller or larger changes in abundance. Apparent changes in abundance were also not consistent between regions, with some catchments (Wimmera and Mallee) recording a large decline in abundance, while others recorded large increases (Corangamite), or no apparent change (e.g. Glenelg-Hopkins, Goulburn-Broken).

While the available data do not give much insight into possible causes of either the apparent statewide decline or the spatial variation in short-term trends in abundance, it is reasonable to speculate that unseasonably dry conditions during the Winter and Spring of 2023 may have contributed to the observed pattern. A deficit in rainfall may have reduced Stubble Quail breeding success in some areas and may also have led to the movement of Stubble Quail around the state in search of more favourable habitat conditions, or into adjacent states. Available data are not adequate for distinguishing between these possibilities or for determining the extent to which the apparent changes are driven by changes in mortality, breeding success or migration. As more survey data accumulate, consideration could be given to moving to a spatio-temporal model of abundance (Camp et al. 2020). Such a model would more efficiently use all of the accumulated survey data and would give more precise estimates of abundance and its temporal trends, both at a statewide and regional scale. Based on previous experience, it is expected that this approach would require a minimum of 3 or 4 years of data to be feasible.

The estimated statewide population of 5.4 million remains large relative to the estimated number of Stubble Quail, which are taken by legal hunting in Victoria each year. For the 2023 hunting season, analysis of telephone survey data led to an estimate of approximately 300 thousand Stubble Quail being taken by hunters in Victoria (Moloney and Flesch 2023b). A harvest of this size represents less than 6% of the current (2024) abundance of Stubble Quail in Victoria. The long-term average annual harvest of 159,000 Stubble Quail (Moloney and Flesch 2023b) represents only 3% of the of the 2024 statewide population. While detailed modelling of responses of Stubble Quail populations to varying harvest rates has not been undertaken, this would seem to be a fairly small proportion of the total population and does not raise concerns about the short-term ecological sustainability of recreational Stubble Quail hunting. Moreover, the current policy of undertaking annual population surveys should mean that decision-makers will be able to continuously monitor the total and regional abundances of Stubble Quail in Victoria and if necessary, adjust hunting arrangements in response to observed changes. Such a reactive approach to the regulation of hunting will help to ensure the long-term ecological sustainability of recreational hunting of Stubble Quail.

When adequate data have been accumulated (i.e. after approximately five annual surveys), consideration could be given to developing a sustainable harvest model for Stubble Quail in Victoria, which includes the impact of hunting. Such a model could be used to assist with decision making regarding hunting arrangements and would increase the transparency of the regulatory process. It should be noted, however, that much of the necessary demographic and ecological data required for a sustainable harvest model are currently lacking. For this reason, reliance on a reactive approach to setting harvest arrangements (where total population estimates are used to revise hunting arrangements for the current season), is likely to be the preferred approach for the foreseeable future.

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Appendix

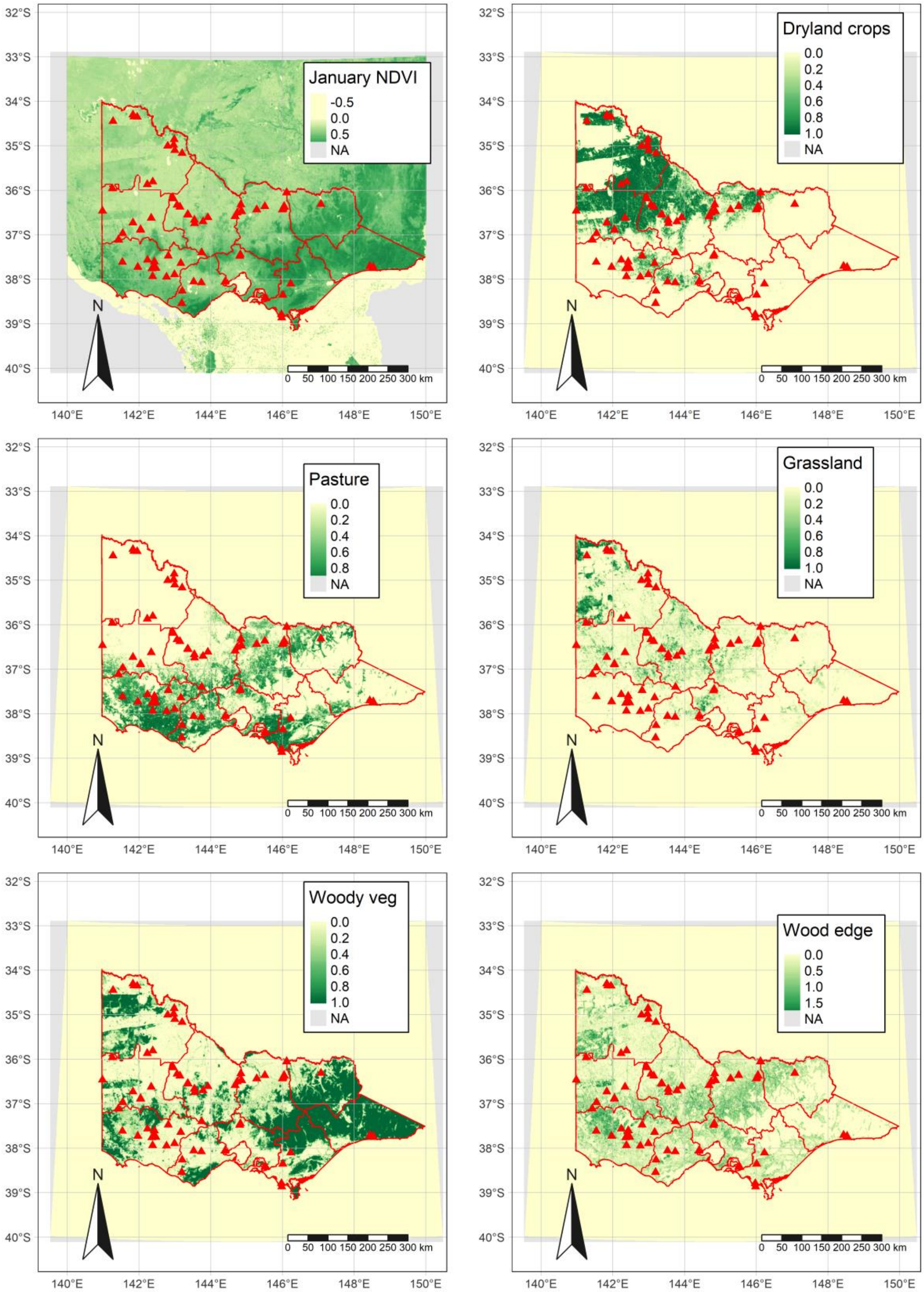

Figure A1. Map of spatially varying covariates used as predictors of density in the density surface model for Stubble Quail in Victoria.

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