

Supplementary Material

Bayesian modelling reveals differences in long-term trends in the harvest of native and introduced species by recreational hunters in Australia

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20 **Table S1.** Questions asked during bi-monthly telephone surveys of ~200 randomly-selected licenced deer hunters in Victoria, from 2009–2019.

Question number	Question	Specified options	Conditions
1	What is the main species of deer you hunt?	Sambar, fallow, red, chital, hog or rusa deer	NA
2	What is your main hunting method?	Stalking, stalking with a gundog, hound hunting, bow hunting, spotlighting	NA
3	Have you been deer hunting in the past two months?	Yes, no	If 'Yes', proceed to question 4
4	How many Deer hunting trips have you taken over this two-month period?	NA	Each trip needs to be treated separately for question 5–11
5	For how many days did you go hunting?	NA	NA
6	How many deer did you harvest?	NA	NA
7	What species were the deer?	Sambar, fallow, red, chital, hog or rusa deer	NA
8	What was the sex of the Deer?	Male, female	NA
9	How were the deer taken?	Stalking, stalking with a gundog, hound hunting, bow hunting, spotlighting	NA
10	Did you hunt on private land or public land?	Public, private, both	NA
11	What was the closest major town to the area you hunted?	NA	NA

22 **Table S2.** Questions asked during telephone surveys of ~200 randomly-selected licenced duck hunters in Victoria, from 2009–2019. Surveys
 23 were conducted after opening weekend, and every two weeks thereafter.

<i>Question number</i>	<i>Question</i>	<i>Specified options</i>	<i>Conditions</i>
1	Did you go duck hunting during period X?	Yes, no	NA
2	Have you been duck hunting in the last week?	Yes, no	If 'Yes', proceed to question 4
3	How many duck hunting trips have you taken over this 1-week period?	NA	Each trip needs to be treated separately for question 4–9
4	For how many days did you go hunting?	NA	NA
5	How many days did you go hunting?	NA	NA
6	How many ducks did you harvest?	NA	NA
7	What species were the ducks?	NA	Include number of each species
8	What type of land did you hunt on?	State Game Reserve, private land, public land	NA
9	What was the closest major town to the area you hunted?	NA	NA

25 **Table S3.** Questions asked during telephone surveys of ~300 randomly-selected stubble quail hunters in Victoria, from 2009–2019. Surveys
 26 were conducted after opening weekend, and every month thereafter.

<i>Question number</i>	<i>Question</i>	<i>Specified options</i>	<i>Conditions</i>
1	Do you use a dog when you hunt for quail?	Yes, no	NA
2	Have you been quail hunting last month?	Yes, no	If 'Yes', proceed to question 3
3	How many quail hunting trips did you take last month?	NA	Each trip needs to be treated separately for question 4–8
4	How many days did you go hunting?	NA	NA
5	How many quail did you harvest?	NA	NA
6	What type of land did you hunt on?	State Game Reserve, private land, public land	NA
7	What type of grasslands was the hunt on?	Stubble, native grass, introduced grass	NA
8	What was the closest major town to the area you hunted?	NA	NA

Table S4. Results from the generalised linear model of the number of deer hunters in Victoria, Australia, from 2009–2019. All estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{deer,c}^{(\ell)}$, where c is January–February	3.124	3.120	3.128
Intercept $\alpha_{deer,c}^{(\ell)}$, where c is March–April	3.197	3.193	3.200
Intercept $\alpha_{deer,c}^{(\ell)}$, where c is May–June	3.244	3.241	3.248
Intercept $\alpha_{deer,c}^{(\ell)}$, where c is July–August	3.281	3.277	3.285
Intercept $\alpha_{deer,c}^{(\ell)}$, where c is September–October	3.310	3.306	3.313
Intercept $\alpha_{deer,c}^{(\ell)}$, where c is November–December	3.317	3.313	3.320
Years since survey started, $\beta_{1,deer}^{(\ell)}$	0.076	0.076	0.077

Table S5. Results from the generalised linear model for the proportion of active deer hunters in Victoria, Australia, from 2009–2019. The standard deviation is on the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{deer,c}^{(a)}$, where c is January–February	-1.852	-	-
		2.042	1.666
Intercept $\alpha_{deer,c}^{(a)}$, where c is March–April	-0.929	-	-
		1.095	0.756
Intercept $\alpha_{deer,c}^{(a)}$, where c is May–June	-0.951	-	-
		1.108	0.766
Intercept $\alpha_{deer,c}^{(a)}$, where c is July–August	-0.718	-	-
		0.894	0.551
Intercept $\alpha_{deer,c}^{(a)}$, where c is September–October	-0.946	-	-
		1.108	0.765
Intercept $\alpha_{deer,c}^{(a)}$, where c is November–December	-1.590	-	-
		1.765	1.397
Years since survey started, $\beta_{1,deer}^{(a)}$.	0.002	-	0.026
		0.020	
Standard deviation of random term.	0.238	0.176	0.310

38 **Table S6.** Results from the generalised linear model for the deer harvest per active deer
39 hunter in Victoria, Australia, from 2009–2019. The standard deviation is on the response
40 scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper
41 bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{deer,c}^{(h)}$, where c is January–February	0.099	- 0.129	0.326
Intercept $\alpha_{deer,c}^{(h)}$, where c is March–April	0.386	0.175	0.588
Intercept $\alpha_{deer,c}^{(h)}$, where c is May–June	0.681	0.478	0.885
Intercept $\alpha_{deer,c}^{(h)}$, where c is July–August	0.652	0.436	0.860
Intercept $\alpha_{deer,c}^{(h)}$, where c is September–October	0.400	0.201	0.616
Intercept $\alpha_{deer,c}^{(h)}$, where c is November–December	0.152	- 0.064	0.375
Years since survey started, $\beta_{1,deer}^{(h)}$.	0.080	0.052	0.108
Standard deviation of random term.	0.332	0.265	0.404

43 **Table S7.** Results from the generalised linear model for the deer hunting days per active deer
44 hunter in Victoria, Australia, from 2009–2019. The standard deviation is on the response
45 scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper
46 bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{deer,c}^{(d)}$, where c is January–February	1.329	1.188	1.472
Intercept $\alpha_{deer,c}^{(d)}$, where c is March–April	1.471	1.342	1.608
Intercept $\alpha_{deer,c}^{(d)}$, where c is May–June	1.606	1.473	1.749
Intercept $\alpha_{deer,c}^{(d)}$, where c is July–August	1.665	1.528	1.786
Intercept $\alpha_{deer,c}^{(d)}$, where c is September–October	1.494	1.363	1.626
Intercept $\alpha_{deer,c}^{(d)}$, where c is November–December	1.197	1.054	1.342
Years since survey started, $\beta_{1,deer}^{(d)}$.	0.002	-0.016	0.020
Standard deviation of random term.	0.215	0.176	0.263

48 **Table S8.** Results from a model that relates to the number of licenced duck hunters in
 49 Victoria, Australia, from 2009–2019. The standard deviation is on the natural scale, all other
 50 estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the
 51 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{duck,c}^{(\ell)}$, where c is March.	-3.695	-3.707	-3.683
Intercept $\alpha_{duck,c}^{(\ell)}$, where c is April.	-3.676	-3.687	-3.664
Intercept $\alpha_{duck,c}^{(\ell)}$, where c is May.	-3.661	-3.673	-3.650
Intercept $\alpha_{duck,c}^{(\ell)}$, where c is June.	-3.655	-3.666	-3.643
Linear term for years since survey started, $\beta_{1,duck}^{(\ell)}$.	0.018	0.016	0.020
Quadratic term for years since survey started, $\beta_{2,duck}^{(\ell)}$.	-0.004	-0.005	-0.004
Reduced daily bag limit, $\beta_{5,duck}^{(\ell)}$.	-0.015	-0.025	-0.003
Standard deviation.	0.388	0.310	0.496

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Table S9. Results from generalised linear model for the proportion of active duck hunters in Victoria, Australia, from 2009–2019. The standard deviation is on the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{duck,c}^{(a)}$, where c is opening weekend.	0.060	-0.158	0.268
Intercept $\alpha_{duck,c}^{(a)}$, where c is March.	-1.002	-1.214	-0.781
Intercept $\alpha_{duck,c}^{(a)}$, where c is April.	-1.267	-1.439	-1.096
Intercept $\alpha_{duck,c}^{(a)}$, where c is May.	-1.417	-1.586	-1.247
Intercept $\alpha_{duck,c}^{(a)}$, where c is June.	-1.232	-1.454	-1.001
Years since survey started, $\beta_{1,duck}^{(a)}$.	-0.058	-0.082	-0.028
El Niño is active, $\beta_{3,duck}^{(a)}$.	-0.017	-0.354	0.329
La Niña is active, $\beta_{4,duck}^{(a)}$.	0.057	-0.168	0.252
Reduced daily bag limit, $\beta_{5,duck}^{(a)}$.	0.093	-0.129	0.285
El Niño is active and reduced daily bag limit, $\beta_{6,duck}^{(a)}$.	-0.117	-0.537	0.288
Standard deviation of random term.	0.241	0.185	0.311

60 **Table S10.** Results from generalised linear model for the duck harvest

61 per active duck hunter in Victoria, Australia, from 2009–2019. The standard deviation is on
 62 the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower
 63 and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{duck,c}^{(h)}$, where c is opening weekend.	1.900	1.748	2.061
Intercept $\alpha_{duck,c}^{(h)}$, where c is March.	2.257	2.098	2.408
Intercept $\alpha_{duck,c}^{(h)}$, where c is April.	2.303	2.182	2.420
Intercept $\alpha_{duck,c}^{(h)}$, where c is May.	2.431	2.313	2.553
Intercept $\alpha_{duck,c}^{(h)}$, where c is June.	2.412	2.253	2.563
Years since survey started, $\beta_{1,duck}^{(h)}$.	-0.007	-0.027	0.011
El Niño is active, $\beta_{3,duck}^{(h)}$.	0.186	-0.036	0.411
La Niña is active, $\beta_{4,duck}^{(h)}$.	0.123	-0.035	0.271
Reduced daily bag limit, $\beta_{5,duck}^{(h)}$.	-0.267	-0.409	-0.118
El Niño is active and reduced daily bag limit, $\beta_{6,duck}^{(h)}$.	-0.338	-0.625	-0.064
Standard deviation of random term.	0.198	0.162	0.236

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Table S11. Results from generalised linear model for the duck hunting days per active duck hunter in Victoria, Australia, from 2009–2019. The standard deviation is on the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{duck,c}^{(d)}$, where c is opening weekend.	-0.002	-0.164	0.167
Intercept $\alpha_{duck,c}^{(d)}$, where c is March.	0.839	0.680	0.987
Intercept $\alpha_{duck,c}^{(d)}$, where c is April.	0.768	0.645	0.900
Intercept $\alpha_{duck,c}^{(d)}$, where c is May.	0.751	0.628	0.877
Intercept $\alpha_{duck,c}^{(d)}$, where c is June.	0.804	0.633	0.974
Years since survey started, $\beta_{1,duck}^{(d)}$.	-0.003	-0.023	0.018
El Niño is active, $\beta_{3,duck}^{(d)}$.	0.107	-0.149	0.353
La Niña is active, $\beta_{4,duck}^{(d)}$.	-0.068	-0.237	0.086
Reduced daily bag limit, $\beta_{5,duck}^{(d)}$.	0.072	-0.084	0.225
El Niño is active and reduced daily bag limit, $\beta_{6,duck}^{(d)}$.	-0.209	-0.528	0.112
Standard deviation of random term.	0.183	0.140	0.231

Table S12. Results from a model that relates to the number of licenced stubble quail hunters in Victoria, Australia, from 2009–2019. The standard deviation is on the natural scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{quail,c}^{(\ell)}$, where c is April.	-3.586	-3.599	-3.573
Intercept $\alpha_{quail,c}^{(\ell)}$, where c is May.	-3.567	-3.579	-3.554
Intercept $\alpha_{quail,c}^{(\ell)}$, where c is June.	-3.560	-3.573	-3.548
Linear term for years since survey started, $\beta_{1,quail}^{(\ell)}$.	0.018	0.016	0.020
Quadratic term for years since survey started, $\beta_{2,quail}^{(\ell)}$.	-0.004	-0.004	-0.003
Standard deviation.	0.489	0.380	0.640

Table S13. Results from a generalised linear model examining the proportion of active stubble quail hunters in Victoria, Australia, from 2009–2019. The standard deviation is on the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{quail,c}^{(a)}$, where c is opening weekend.	-2.749	-3.186	-2.337
Intercept $\alpha_{quail,c}^{(a)}$, where c is April.	-2.106	-2.341	-1.860
Intercept $\alpha_{quail,c}^{(a)}$, where c is May.	-2.365	-2.610	-2.131
Intercept $\alpha_{quail,c}^{(a)}$, where c is June.	-2.389	-2.665	-2.135
Years since survey started, $\beta_{1,quail}^{(a)}$.	-0.042	-0.082	-0.001
El Niño is active, $\beta_{3,quail}^{(a)}$.	-0.366	-0.656	-0.079
La Niña is active, $\beta_{4,quail}^{(a)}$.	0.708	0.355	1.057
Standard deviation of random term	0.305	0.201	0.431

Table S14. Results from a generalised linear model for the stubble quail harvest per active hunter in Victoria, Australia, from 2009–2019. The standard deviation is on the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{quail,c}^{(h)}$, where c is opening weekend.	2.157	1.484	2.860
Intercept $\alpha_{quail,c}^{(h)}$, where c is April.	2.504	2.088	2.967
Intercept $\alpha_{quail,c}^{(h)}$, where c is May.	2.492	2.056	2.898
Intercept $\alpha_{quail,c}^{(h)}$, where c is June.	2.544	2.107	2.987
Years since survey started, $\beta_{1,quail}^{(h)}$.	0.026	-0.046	0.092
El Niño is active, $\beta_{3,quail}^{(h)}$.	-0.028	-0.516	0.437
La Niña is active, $\beta_{4,quail}^{(h)}$.	0.524	-0.033	1.221
Standard deviation of random term	0.657	0.507	0.840

Table S15. Results from a generalised linear model for hunting days per active stubble quail hunter in Victoria, Australia, from 2009–2019. The standard deviation is on the response scale, all other estimates are on the logarithmic scale. LB and UB are the lower and upper bounds for the 95% credible interval respectively.

<i>Parameter</i>	<i>Median</i>	<i>LB</i>	<i>UB</i>
Intercept $\alpha_{quail,c}^{(d)}$, where c is opening weekend.	-1.067	-1.673	-0.497
Intercept $\alpha_{quail,c}^{(d)}$, where c is April.	0.621	0.426	0.815
Intercept $\alpha_{quail,c}^{(d)}$, where c is May.	0.503	0.309	0.706
Intercept $\alpha_{quail,c}^{(d)}$, where c is June.	0.636	0.408	0.831
Years since survey started, $\beta_{1,quail}^{(d)}$.	0.036	0.003	0.070
El Niño is active, $\beta_{3,quail}^{(d)}$.	0.269	0.031	0.511
La Niña is active, $\beta_{4,quail}^{(d)}$.	0.122	-0.149	0.433
Standard deviation of random term	0.252	0.167	0.347

Fig. S1. Fitted model estimates for the proportion of active deer hunters per survey (two-month period) in Victoria, Australia, from 2009–2019. The black points are the point estimates from each hunter survey based on frequentist methods. The blue points are the survey estimates from the model with the vertical lines representing the 95% credible intervals.

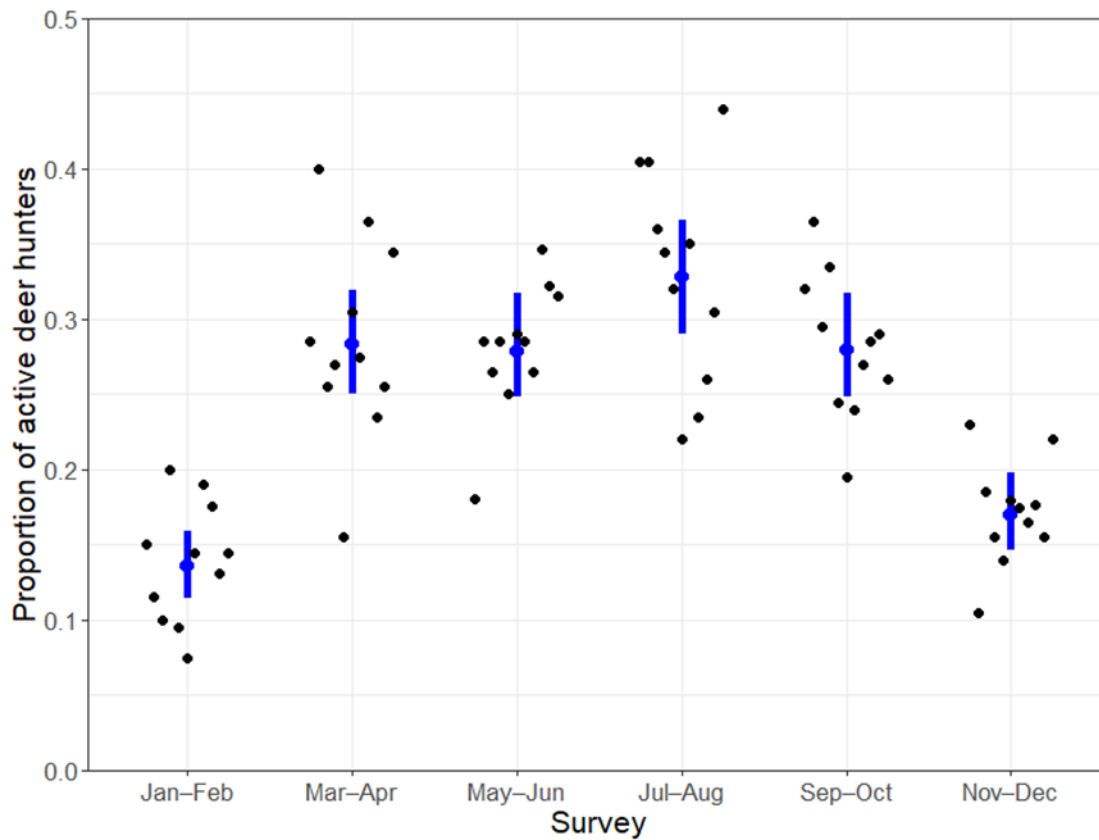


Fig. S2. Fitted model estimates for the proportion of active duck hunters in Victoria, Australia, per survey group (month) from 2009–2019. The blue points are the point estimates from each hunter survey based on frequentist methods and the orange points are the survey estimates from the model with the vertical lines representing 95% credible intervals.

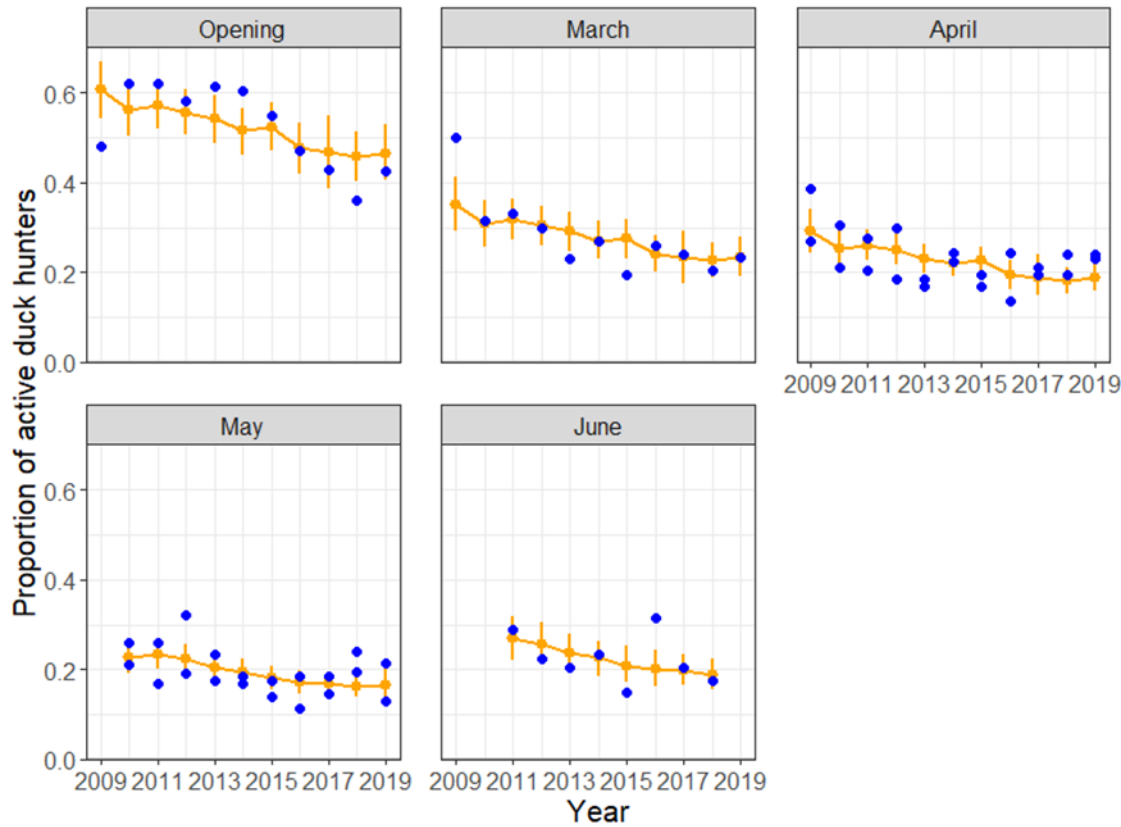


Fig. S3. Fitted model estimates for the proportion of active stubble quail hunters in Victoria, Australia, per survey from 2009–2019, separated into environmental conditions. The blue points are the point estimates from each hunter survey based on frequentist methods in chronological order from left to right. The orange points are the survey estimates from the model with the vertical lines representing the 95% credible intervals.

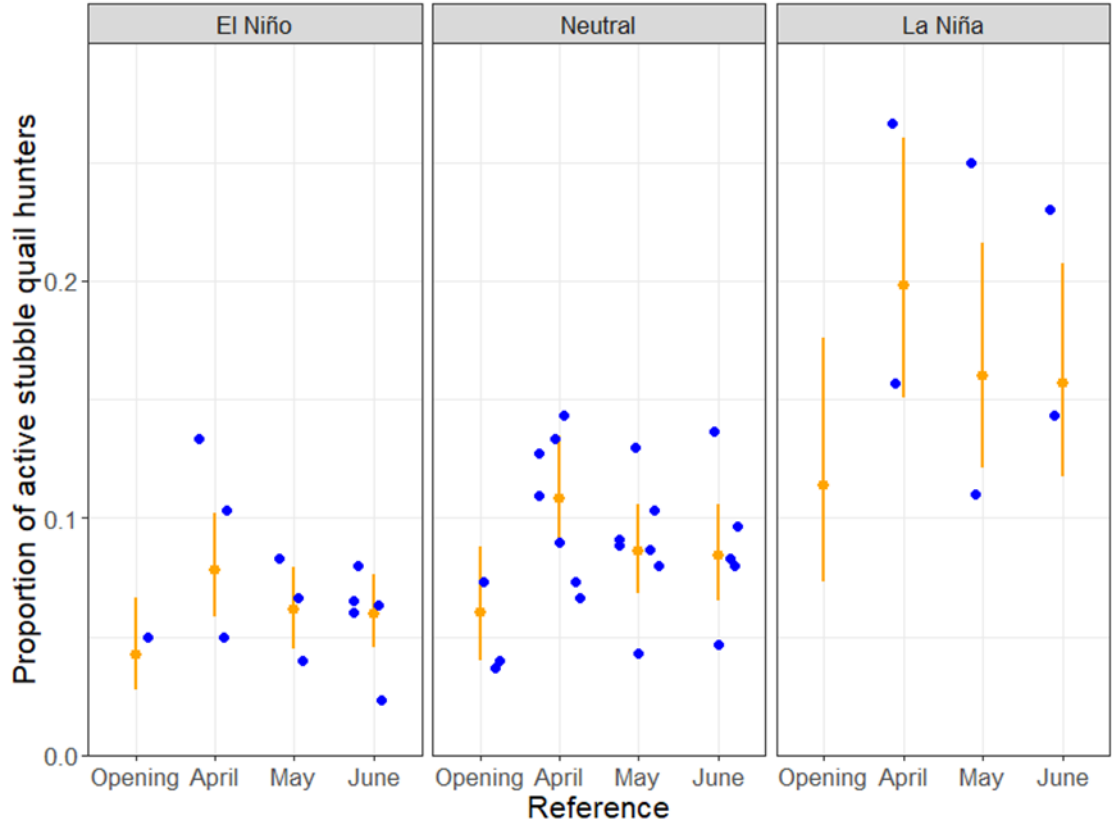
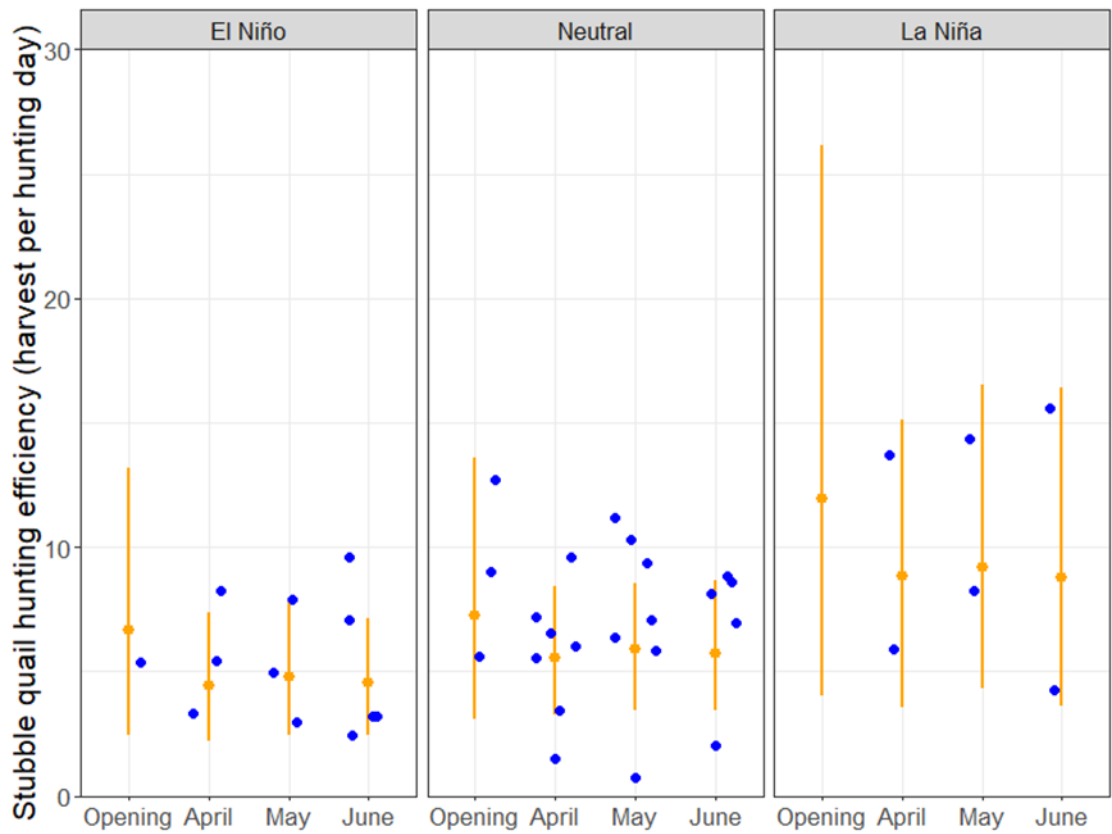


Fig. S4. Fitted model estimates for stubble quail hunting efficiency in Victoria, Australia, under the different environmental conditions observed from 2009–2019. The blue points are the point estimates from each hunter survey arranged in chronological order from left to right. The orange points are the survey estimates from the model with the vertical lines representing the 95% credible intervals.



123 **Code S1. JAGS code for deer model**

```
124    DeerModelT <- function(){  
125       # Priors  
126       for(i in 1:6){  
127           alphaH[i] ~ dunif(-10, 10)  
128           alphaD[i] ~ dunif(-10, 10)  
129           alphaL[i] ~ dunif(-10, 10)  
130           gamma[i] ~ dunif(-10, 10)  
131       }  
132       for(i in 1:1){  
133           betaH[i] ~ dunif(-10, 10)  
134           betaD[i] ~ dunif(-10, 10)  
135           betaL[i] ~ dunif(-10, 10)  
136           delta[i] ~ dunif(-10, 10)  
137       }  
138       betaL[2] ~ dunif(-10, 10)  
139       for(i in 1:nSurvey){  
140           epsH[i] ~ dnorm(0, tauH)  
141           epsT[i] ~ dnorm(0, tauT)  
142           epsD[i] ~ dnorm(0, tauD)  
143           # epsL[i] ~ dnorm(0, tauL)  
144       }  
145       ## Random effects  
146       sL ~ dgamma(0.0001, 0.0001)  
147       tauL <- pow(sL, -2)
```

```

148   sT ~ dgamma(0.0001, 0.0001)
149   tauT <- pow(sT, -2)
150   sH ~ dgamma(0.0001, 0.0001)
151   tauH <- pow(sH, -2)
152   sD ~ dgamma(0.0001, 0.0001)
153   tauD <- pow(sD, -2)
154   # Likelihoods
155   for(i in 1:nSurvey){
156     # Licences
157     nLic[i] ~ dnorm(predL[i], tauL)
158     log(predL[i]) <- alphaL[Survey[i]] + betaL[1]*Year[i] + betaL[2]*Year[i]*Year[i] +
159     log(1000)
160     log(ExpL[i]) <- mean(alphaL[1:6]) + betaL[1]*Year[i] + betaL[2]*Year[i]*Year[i] +
161     log(1000) #Expected deseasoned Licences at a survey
162     # Active hunters
163     Hunters[i] ~ dbin(pHunt[i], Resp[i])
164     logit(pHunt[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + epsT[i]
165     # Harvest
166     Harv[i] ~ dpois(HpAH[i]*Hunters[i])
167     log(HpAH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + epsH[i]
168     # Hunting days
169     DpAH[i] <- lambda[i]*exp(lambda[i])/(exp(lambda[i]) - 1)
170     log(lambda[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + epsD[i]
171     ## Zeroes trick
172     z[i] ~ dpois(phi[i])

```

```

173     phi[i] <- logfact(Days[i]) + Hunters[i]*log(exp(lambda[i])-1) - Days[i]*log(lambda[i]) -
174     log(LL[i])
175     LL[i] <- sum(SS[i, 1:(Hunters[i] + 1)])
176     for(j in 0:Hunters[i]){
177         SS[i, j + 1] <- pow(-1, j)*pow(Hunters[i] - j, Days[i])*exp(logfact(Hunters[i]) -
178 (logfact(j) + logfact(Hunters[i] - j)))
179     }
180     for(j in (Hunters[i] + 1):MaxHunt){
181         SS[i, j + 1] <- 0
182     }
183     # Derived statistics
184     THunt[i] <- pHunt[i]*nLic[i] # Total active hunters per survey
185     THarv[i] <- HpAH[i]*THunt[i] # Total harvest per survey
186     TDays[i] <- DpAH[i]*THunt[i] # Total hunting days per survey
187     HpL[i] <- THarv[i]/nLic[i] # Harvest per licence per survey
188     DpL[i] <- TDays[i]/nLic[i] # Hunting days per licence per survey
189     HpD[i] <- THarv[i]/TDays[i] # Harvest per day per survey
190     logit(ExpP[i]) <- gamma[Survey[i]] + delta[1]*Time[i] # Expected proportion active
191     hunters per survey
192     ExpHunt[i] <- ExpP[i]*nLic[i] # Expected number of active hunters per survey
193     log(ExpHpH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] # Expected harvest per active
194     hunter per survey
195     ExpHarv[i] <- ExpHpH[i]*ExpHunt[i] # Expected harvest per survey
196     ExpHpL[i] <- ExpHpH[i]*ExpP[i] # Expected harvest per licence holder per survey

```

```

197     log(ExpHpHnS[i]) <- mean(alphaH[1:6]) + betaH[1]*Time[i] # Expected deseasoned
198     harvest per active hunter per survey
199     ExpHarvnS[i] <- ExpHpHnS[i]*ExpHunt[i] # Expected deseasoned harvest per survey
200     log(Explam[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] # Expected lambda hunting days
201     per active hunter per survey
202     ExpDpH[i] <- Explam[i]*exp(Explam[i])/(exp(Explam[i]) - 1) # Expected hunting days
203     per active hunter per survey
204     ExpDays[i] <- ExpDpH[i]*ExpHunt[i] # Expected hunting days per survey
205     ExpDpL[i] <- ExpDpH[i]*ExpP[i] # Expected hunting days per licence holder per survey
206     log(ExplamnS[i]) <- mean(alphaD[1:6]) + betaD[1]*Time[i] # Expected lambda
207     deseasoned hunting days per active hunter per survey
208     ExpDpHnS[i] <- ExplamnS[i]*exp(ExplamnS[i])/(exp(ExplamnS[i]) - 1) # Expected
209     deseasoned hunting days per active hunter per survey
210     ExpDaysnS[i] <- ExpDpHnS[i]*ExpHunt[i] # Expected deseasoned hunting days per
211     survey
212     ExpHpD[i] <- ExpHpH[i]/ExpDpH[i] # Expected efficiency
213     ExpHpDnS[i] <- ExpHpHnS[i]/ExpDpHnS[i] # Expected deseasoned efficiency
214 }
215 # Yearly totals
216 for(j in 1:nYears){
217     TTHarv[j] <- sum(THarv[1:6 + 6*(j-1)])
218     TTDays[j] <- sum(TDays[1:6 + 6*(j-1)])
219     THpL[j] <- sum(HpL[1:6 + 6*(j-1)])
220     TDpL[j] <- sum(DpL[1:6 + 6*(j-1)])
221     THpD[j] <- THpL[j]/TDpL[j]

```



```

222     TExpHarv[j] <- sum(ExpHarv[1:6 + 6*(j-1)])
223     TExpDays[j] <- sum(ExpDays[1:6 + 6*(j-1)])
224     TExpHpL[j] <- sum(ExpHpL[1:6 + 6*(j-1)])
225     TExpDpL[j] <- sum(ExpDpL[1:6 + 6*(j-1)])
226     TExpHpD[j] <- TExpHpL[j]/TExpDpL[j]
227 }
228 # Average growth
229 HarvGrowSurv <- exp(mean(log(ExpHarv[2:nSurvey]/ExpHarv[1:(nSurvey-1)])))
230 HarvGrowYear <- exp(mean(log(TExpHarv[2:nYears]/TExpHarv[1:(nYears-1)])))
231 }
232

```

233 **Code S2. JAGS code for duck model**

```
234   DuckModelT <- function(){  
235     # Priors  
236     for(i in 1:5){  
237       alphaH[i] ~ dunif(-10, 10)  
238       alphaD[i] ~ dunif(-10, 10)  
239       alphaL[i] ~ dunif(-10, 10)  
240       gamma[i] ~ dunif(-10, 10)  
241     }  
242     for(i in 1:5){  
243       betaH[i] ~ dunif(-10, 10)  
244       betaD[i] ~ dunif(-10, 10)  
245       betaL[i] ~ dunif(-10, 10)  
246       delta[i] ~ dunif(-10, 10)  
247     }  
248     for(i in 1:nSurvey){  
249       epsH[i] ~ dnorm(0, tauH)  
250       epsT[i] ~ dnorm(0, tauT)  
251       epsD[i] ~ dnorm(0, tauD)  
252       # epsL[i] ~ dnorm(0, tauL)  
253     }  
254     # for(i in 1:nYears){  
255       #   epsLY[i] ~ dnorm(0, tauLY)  
256       # }  
257     ## Random effects
```

```

258   sL ~ dgamma(0.0001, 0.0001)
259   tauL <- pow(sL, -2)
260   sT ~ dgamma(0.0001, 0.0001)
261   tauT <- pow(sT, -2)
262   sH ~ dgamma(0.0001, 0.0001)
263   tauH <- pow(sH, -2)
264   sD ~ dgamma(0.0001, 0.0001)
265   tauD <- pow(sD, -2)
266   # Likelihoods
267   for(i in 1:nmYear){
268     # Licences
269     mLic[i] ~ dnorm(predL[i], tauL)
270     log(predL[i]) <- alphaL[mMonth[i]] + betaL[2]*mYear[i] + betaL[3]*mYear[i]*mYear[i]
271     + betaL[4]*mRedBag[i] + log(1000)
272     log(ExpL[i]) <- mean(alphaL[1:4]) + betaL[2]*mYear[i] + betaL[3]*mYear[i]*mYear[i] +
273     betaL[4]*mRedBag[i] + log(1000) # Expected deseasoned Licences at a survey
274   }
275   for(i in 1:nSurvey){
276     # Active hunters
277     Hunters[i] ~ dbin(pHunt[i], Resp[i])
278     logit(pHunt[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + delta[2]*ElNino[i] +
279     delta[3]*LaNina[i] + delta[4]*RedBag[i] + delta[5]*ElNino[i]*RedBag[i] + epsT[i]
280     # Harvest
281     Harv[i] ~ dpois(HpAH[i]*Hunters[i])

```

```

282     log(HpAH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
283     betaH[3]*LaNina[i] + betaH[4]*RedBag[i] + betaH[5]*ElNino[i]*RedBag[i] + epsH[i]
284     # Hunting days
285     DpAH[i] <- lambda[i]*exp(lambda[i])/(exp(lambda[i]) - 1)
286     log(lambda[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
287     betaD[3]*LaNina[i] + betaD[4]*RedBag[i] + betaD[5]*ElNino[i]*RedBag[i] + epsD[i]
288     ## Zeroes trick
289     z[i] ~ dpois(phi[i])
290     phi[i] <- logfact(Days[i]) + Hunters[i]*log(exp(lambda[i])-1) - Days[i]*log(lambda[i]) -
291     log(LL[i]) + 10000
292     LL[i] <- sum(SS[i, 1:(Hunters[i] + 1)])
293     for(j in 0:Hunters[i]){
294         SS[i, j + 1] <- pow(-1, j)*pow(Hunters[i] - j, Days[i])*exp(logfact(Hunters[i]) -
295     (logfact(j) + logfact(Hunters[i]) - j))
296     }
297     for(j in (Hunters[i] + 1):MaxHunt){
298         SS[i, j + 1] <- 0
299     }
300     # Derived statistics
301     THunt[i] <- pHunt[i]*nLic[i] # Total active hunters per survey
302     THarv[i] <- HpAH[i]*THunt[i] # Total harvest per survey
303     TDays[i] <- DpAH[i]*THunt[i] # Total hunting days per survey
304     HpL[i] <- THarv[i]/nLic[i] # Harvest per licence per survey
305     DpL[i] <- TDays[i]/nLic[i] # Hunting days per licence per survey
306     HpD[i] <- THarv[i]/TDays[i] # Harvest per day per survey

```

```

307     logit(ExpP[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + delta[2]*ElNino[i] +
308     delta[3]*LaNina[i] + delta[4]*RedBag[i] + delta[5]*ElNino[i]*RedBag[i]# Expected
309     proportion active hunters per survey
310     ExpHunt[i] <- ExpP[i]*nLic[i] # Expected number of active hunters per survey
311     log(ExpHpH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
312     betaH[3]*LaNina[i] + betaH[4]*RedBag[i] + betaH[5]*ElNino[i]*RedBag[i] # Expected
313     harvest per active hunter per survey
314     ExpHarv[i] <- ExpHpH[i]*ExpHunt[i] # Expected harvest per survey
315     ExpHpL[i] <- ExpHpH[i]*ExpP[i] # Expected harvest per licence holder per survey
316     log(ExpHpHnS[i]) <- mean(alphaH[1:5]) + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
317     betaH[3]*LaNina[i] + betaH[4]*RedBag[i] + betaH[5]*ElNino[i]*RedBag[i]# Expected
318     deseasoned harvest per active hunter per survey
319     ExpHarvnS[i] <- ExpHpHnS[i]*ExpHunt[i] # Expected deseasoned harvest per survey
320     log(Explam[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
321     betaD[3]*LaNina[i] + betaD[4]*RedBag[i] + betaD[5]*ElNino[i]*RedBag[i] # Expected
322     lambda hunting days per active hunter per survey
323     ExpDpH[i] <- Explam[i]*exp(Explam[i])/(exp(Explam[i]) - 1) # Expected hunting days
324     per active hunter per survey
325     ExpDays[i] <- ExpDpH[i]*ExpHunt[i] # Expected hunting days per survey
326     ExpDpL[i] <- ExpDpH[i]*ExpP[i] # Expected hunting days per licence holder per survey
327     log(ExplamnS[i]) <- mean(alphaD[1:5]) + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
328     betaD[3]*LaNina[i] + betaD[4]*RedBag[i] + betaD[5]*ElNino[i]*RedBag[i] # Expected
329     lambda deseasoned hunting days per active hunter per survey
330     ExpDpHnS[i] <- ExplamnS[i]*exp(ExplamnS[i])/(exp(ExplamnS[i]) - 1)# Expected
331     deseasoned hunting days per active hunter per survey

```

```

332     ExpDaysnS[i] <- ExpDpHnS[i]*ExpHunt[i] # Expected deseasoned hunting days per
333 survey
334     ExpHpD[i] <- ExpHpH[i]/ExpDpH[i] # Expected efficiency
335     ExpHpDnS[i] <- ExpHpHnS[i]/ExpDpHnS[i] # Expected deseasoned efficiency
336 }
337 # Yearly totals
338 for(j in 1:nYears){
339     TTHarv[j] <- sum(THarv[SurvStart[j]:SurvEnd[j]])
340     TTDays[j] <- sum(TDays[SurvStart[j]:SurvEnd[j]])
341     THpL[j] <- sum(HpL[SurvStart[j]:SurvEnd[j]])
342     TDpL[j] <- sum(DpL[SurvStart[j]:SurvEnd[j]])
343     THpD[j] <- THpL[j]/TDpL[j]
344     TExpHarv[j] <- sum(ExpHarv[SurvStart[j]:SurvEnd[j]])
345     TExpDays[j] <- sum(ExpDays[SurvStart[j]:SurvEnd[j]])
346     TExpHpL[j] <- sum(ExpHpL[SurvStart[j]:SurvEnd[j]])
347     TExpDpL[j] <- sum(ExpDpL[SurvStart[j]:SurvEnd[j]])
348     TExpHpD[j] <- TExpHpL[j]/TExpDpL[j]
349 }
350 # Average growth
351 HarvGrowSurv <- exp(mean(log(ExpHarv[2:nSurvey]/ExpHarv[1:(nSurvey-1)])))
352 HarvGrowYear <- exp(mean(log(TExpHarv[2:nYears]/TExpHarv[1:(nYears-1)])))
353 EffGrowYear <- exp(mean(log(TExpHpD[2:nYears]/TExpHpD[1:(nYears-1)])))
354 }
355

```

356 **Code S3. JAGS code for quail model**

```
357 QuailModelT <- function(){
358   # Priors
359   for(i in 1:4){
360     alphaH[i] ~ dunif(-10, 10)
361     alphaD[i] ~ dunif(-10, 10)
362     alphaL[i] ~ dunif(-10, 10)
363     gamma[i] ~ dunif(-10, 10)
364   }
365   for(i in 1:3){
366     betaH[i] ~ dunif(-10, 10)
367     betaD[i] ~ dunif(-10, 10)
368     betaL[i] ~ dunif(-10, 10)
369     delta[i] ~ dunif(-10, 10)
370   }
371   for(i in 1:nSurvey){
372     epsH[i] ~ dnorm(0, tauH)
373     epsT[i] ~ dnorm(0, tauT)
374     epsD[i] ~ dnorm(0, tauD)
375     # epsL[i] ~ dnorm(0, tauL)
376   }
377   # for(i in 1:nYears){
378   #   epsLY[i] ~ dnorm(0, tauLY)
379   # }
380   ## Random effects
```

```

381   sL ~ dgamma(0.0001, 0.0001)
382   tauL <- pow(sL, -2)
383   sT ~ dgamma(0.0001, 0.0001)
384   tauT <- pow(sT, -2)
385   sH ~ dgamma(0.0001, 0.0001)
386   tauH <- pow(sH, -2)
387   sD ~ dgamma(0.0001, 0.0001)
388   tauD <- pow(sD, -2)
389   # Likelihoods
390   for(i in 1:nmYear){
391     # Licences
392     mLic[i] ~ dnorm(predL[i], tauL)
393     log(predL[i]) <- alphaL[mMonth[i]] + betaL[1]*mYear[i] + betaL[2]*mYear[i]*mYear[i]
394     + log(1000)
395     log(ExpL[i]) <- mean(alphaL[1:3]) + betaL[1]*mYear[i] + betaL[2]*mYear[i]*mYear[i] +
396     log(1000) # Expected deseasoned Licences at a survey
397   }
398   for(i in 1:nSurvey){
399     # Active hunters
400     Hunters[i] ~ dbin(pHunt[i], Resp[i])
401     logit(pHunt[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + delta[2]*ElNino[i] +
402     delta[3]*LaNina[i] + epsT[i]
403     # Harvest
404     Harv[i] ~ dpois(HpAH[i]*Hunters[i])

```



```

405     log(HpAH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
406     betaH[3]*LaNina[i] + epsH[i]
407     # Hunting days
408     DpAH[i] <- lambda[i]*exp(lambda[i])/(exp(lambda[i]) - 1)
409     log(lambda[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
410     betaD[3]*LaNina[i] + epsD[i]
411     ## Zeroes trick
412     z[i] ~ dpois(phi[i])
413     phi[i] <- logfact(Days[i]) + Hunters[i]*log(exp(lambda[i])-1) - Days[i]*log(lambda[i]) -
414     log(LL[i]) + 100000
415     LL[i] <- sum(SS[i, 1:(Hunters[i] + 1)])
416     for(j in 0:Hunters[i]){
417         SS[i, j + 1] <- pow(-1, j)*pow(Hunters[i] - j, Days[i])*exp(logfact(Hunters[i]) -
418     (logfact(j) + logfact(Hunters[i]) - j))
419     }
420     for(j in (Hunters[i] + 1):MaxHunt){
421         SS[i, j + 1] <- 0
422     }
423     # Derived statistics
424     THunt[i] <- pHunt[i]*nLic[i] # Total active hunters per survey
425     THarv[i] <- HpAH[i]*THunt[i] # Total harvest per survey
426     TDays[i] <- DpAH[i]*THunt[i] # Total hunting days per survey
427     HpL[i] <- THarv[i]/nLic[i] # Harvest per licence per survey
428     DpL[i] <- TDays[i]/nLic[i] # Hunting days per licence per survey
429     HpD[i] <- THarv[i]/TDays[i] # Harvest per day per survey

```

```

430     logit(ExpP[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + delta[2]*ElNino[i] +
431     delta[3]*LaNina[i]# Expected proportion active hunters per survey
432     ExpHunt[i] <- ExpP[i]*nLic[i] # Expected number of active hunters per survey
433     log(ExpHpH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
434     betaH[3]*LaNina[i]# Expected harvest per active hunter per survey
435     ExpHarv[i] <- ExpHpH[i]*ExpHunt[i] # Expected harvest per survey
436     ExpHpL[i] <- ExpHpH[i]*ExpP[i] # Expected harvest per licence holder per survey
437     log(ExpHpHnS[i]) <- mean(alphaH[1:4]) + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
438     betaH[3]*LaNina[i]# Expected deseasoned harvest per active hunter per survey
439     ExpHarvnS[i] <- ExpHpHnS[i]*ExpHunt[i] # Expected deseasoned harvest per survey
440     log(Explam[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
441     betaD[3]*LaNina[i]# Expected lambda hunting days per active hunter per survey
442     ExpDpH[i] <- Explam[i]*exp(Explam[i])/(exp(Explam[i]) - 1) # Expected hunting days
443     per active hunter per survey
444     ExpDays[i] <- ExpDpH[i]*ExpHunt[i] # Expected hunting days per survey
445     ExpDpL[i] <- ExpDpH[i]*ExpP[i] # Expected hunting days per licence holder per survey
446     log(ExplamnS[i]) <- mean(alphaD[1:4]) + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
447     betaD[3]*LaNina[i]# Expected lambda deseasoned hunting days per active hunter per survey
448     ExpDpHnS[i] <- ExplamnS[i]*exp(ExplamnS[i])/(exp(ExplamnS[i]) - 1)# Expected
449     deseasoned hunting days per active hunter per survey
450     ExpDaysnS[i] <- ExpDpHnS[i]*ExpHunt[i] # Expected deseasoned hunting days per
451     survey
452     ExpHpD[i] <- ExpHpH[i]/ExpDpH[i] # Expected efficiency
453     ExpHpDnS[i] <- ExpHpHnS[i]/ExpDpHnS[i] # Expected deseasoned efficiency
454 }

```

```

455 # Yearly totals
456 for(j in 1:nYears){
457   TTHarv[j] <- sum(THarv[SurvStart[j]:SurvEnd[j]])
458   TTDays[j] <- sum(TDays[SurvStart[j]:SurvEnd[j]])
459   THpL[j] <- sum(HpL[SurvStart[j]:SurvEnd[j]])
460   TDpL[j] <- sum(DpL[SurvStart[j]:SurvEnd[j]])
461   THpD[j] <- THpL[j]/TDpL[j]
462   TExpHarv[j] <- sum(ExpHarv[SurvStart[j]:SurvEnd[j]])
463   TExpDays[j] <- sum(ExpDays[SurvStart[j]:SurvEnd[j]])
464   TExpHpL[j] <- sum(ExpHpL[SurvStart[j]:SurvEnd[j]])
465   TExpDpL[j] <- sum(ExpDpL[SurvStart[j]:SurvEnd[j]])
466   TExpHpD[j] <- TExpHpL[j]/TExpDpL[j]
467 }
468 # Average growth
469 HarvGrowSurv <- exp(mean(log(ExpHarv[2:nSurvey]/ExpHarv[1:(nSurvey-1)])))
470 HarvGrowYear <- exp(mean(log(TExpHarv[2:nYears]/TExpHarv[1:(nYears-1)])))
471 EffGrowYear <- exp(mean(log(TExpHpD[2:nYears]/TExpHpD[1:(nYears-1)])))
472 }
473

```