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Wildlife Research

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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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*

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

Question number	*Question*	*Specified options*	*Conditions*
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*

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

Question number	*Question*	*Specified options*	*Conditions*
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.

Parameter	*Median*	*LB*	*UB*
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.

Parameter	*Median*	*LB*	*UB*
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*	*-0.020*	*0.026*
Standard deviation of random term.	*0.238*	*0.176*	*0.310*

Table S6. Results from the generalised linear model for the deer harvest per active deer 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.

Parameter	*Median*	*LB*	*UB*
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*

Table S7. Results from the generalised linear model for the deer hunting days per active deer 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.

Parameter	*Median*	*LB*	*UB*
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*

Table S8. Results from a model that relates to the number of licenced duck 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.

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

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.

Parameter	*Median*	*LB*	*UB*
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*

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

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

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.

Parameter	*Median*	*LB*	*UB*
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.

Parameter	*Median*	*LB*	*UB*
Intercept $\alpha^{(\ell)}_{quail,c}$, where c is April.	*-3.586*	*-3.599*	*-3.573*
Intercept $\alpha^{(\ell)}_{quail,c}$, where c is May.	*-3.567*	*-3.579*	*-3.554*
Intercept $\alpha^{(\ell)}_{quail,c}$, where c is June.	*-3.560*	*-3.573*	*-3.548*
Linear term for years since survey started, $\beta^{(\ell)}_{1,quail}$.	*0.018*	*0.016*	*0.020*
Quadratic term for years since survey started, $\beta^{(\ell)}_{2,quail}$.	*-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.

Parameter	*Median*	*LB*	*UB*
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.

Parameter	*Median*	*LB*	*UB*
Intercept $\alpha^{(h)}_{quail,c}$, where c is opening weekend.	*2.157*	*1.484*	*2.860*
Intercept $\alpha^{(h)}_{quail,c}$, where c is April.	*2.504*	*2.088*	*2.967*
Intercept $\alpha^{(h)}_{quail,c}$, where c is May.	*2.492*	*2.056*	*2.898*
Intercept $\alpha^{(h)}_{quail,c}$, where c is June.	*2.544*	*2.107*	*2.987*
Years since survey started, $\beta^{(h)}_{1,quail}$.	*0.026*	*-0.046*	*0.092*
El Niño is active, $\beta^{(h)}_{3,quail}$.	*-0.028*	*-0.516*	*0.437*
La Niña is active, $\beta^{(h)}_{4,quail}$.	*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.

Parameter	*Median*	*LB*	*UB*
Intercept $\alpha^{(d)}_{quail,c}$, where c is opening weekend.	*-1.067*	*-1.673*	*-0.497*
Intercept $\alpha^{(d)}_{quail,c}$, where c is April.	*0.621*	*0.426*	*0.815*
Intercept $\alpha^{(d)}_{quail,c}$, where c is May.	*0.503*	*0.309*	*0.706*
Intercept $\alpha^{(d)}_{quail,c}$, where c is June.	*0.636*	*0.408*	*0.831*
Years since survey started, $\beta^{(d)}_{1,quail}$.	*0.036*	*0.003*	*0.070*
El Niño is active, $\beta^{(d)}_{3,quail}$.	*0.269*	*0.031*	*0.511*
La Niña is active, $\beta^{(d)}_{4,quail}$.	*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.

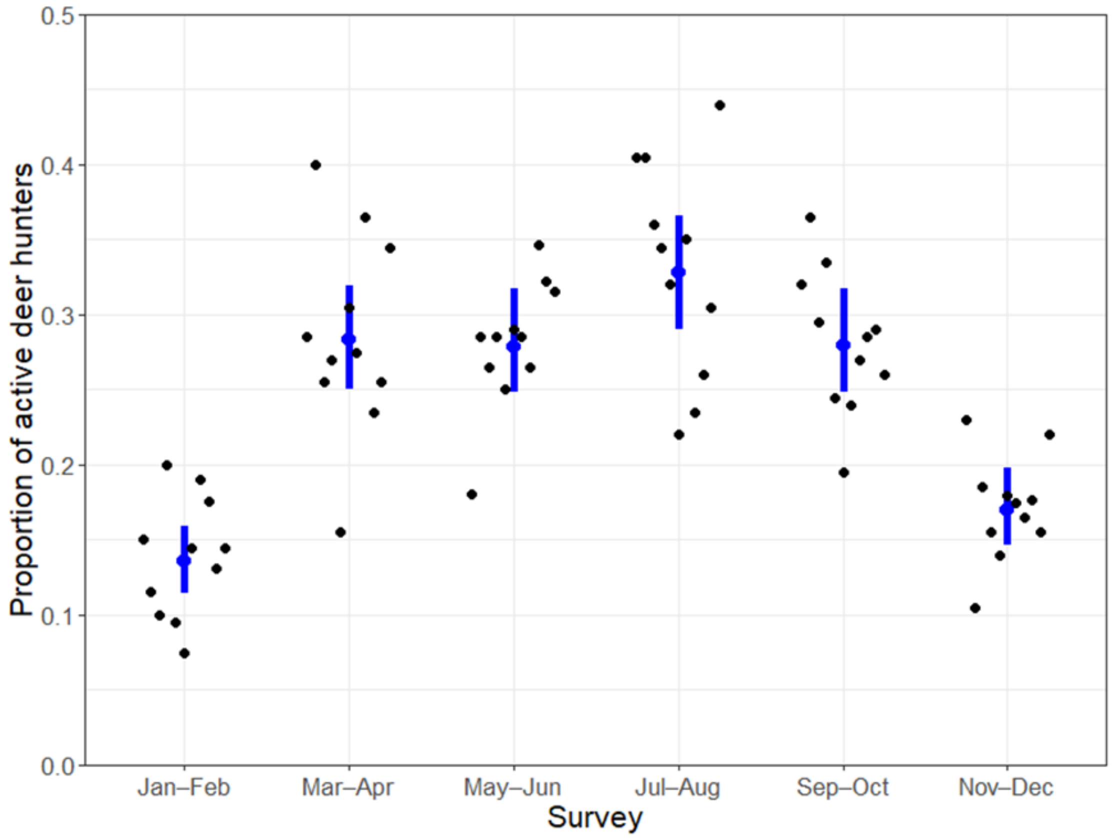


Fig. S2. Fitted model estimates for the proportion of active duck hunters in Victoria, Australia, per survey group (month) from 2009−2019. The blue points are the point estimates from each hunter survey based on frequentist methods and the orange points are the survey estimates from the model with the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

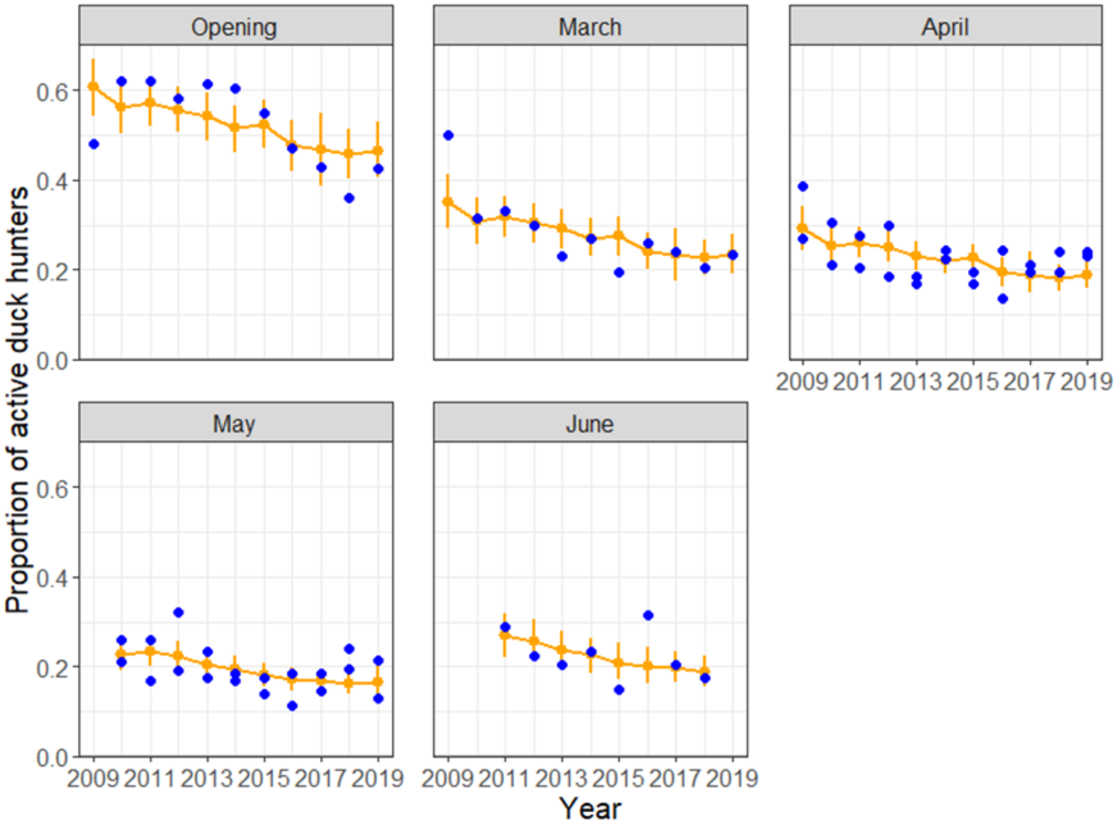


Fig. S3. Fitted model estimates for the proportion of active stubble quail hunters in Victoria, Australia, per survey from 2009−2019, separated into environmental conditions. The blue points are the point estimates from each hunter survey based on frequentist methods in chronological order from left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

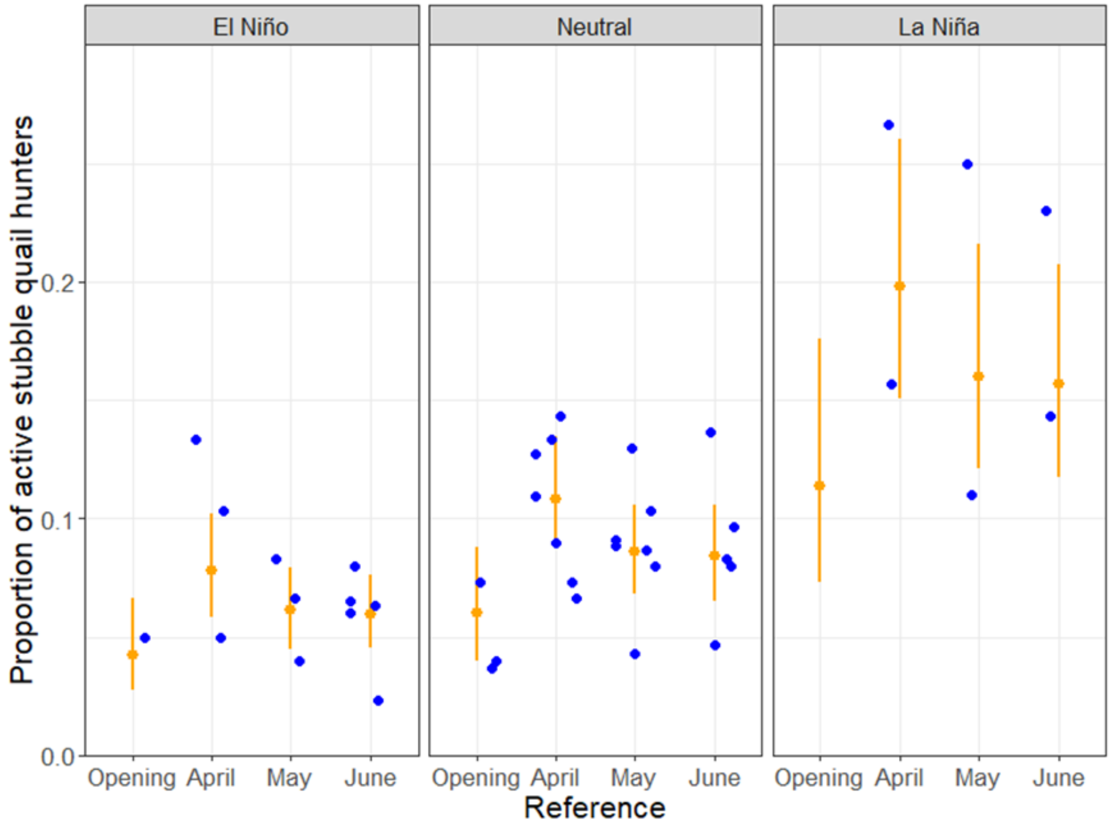
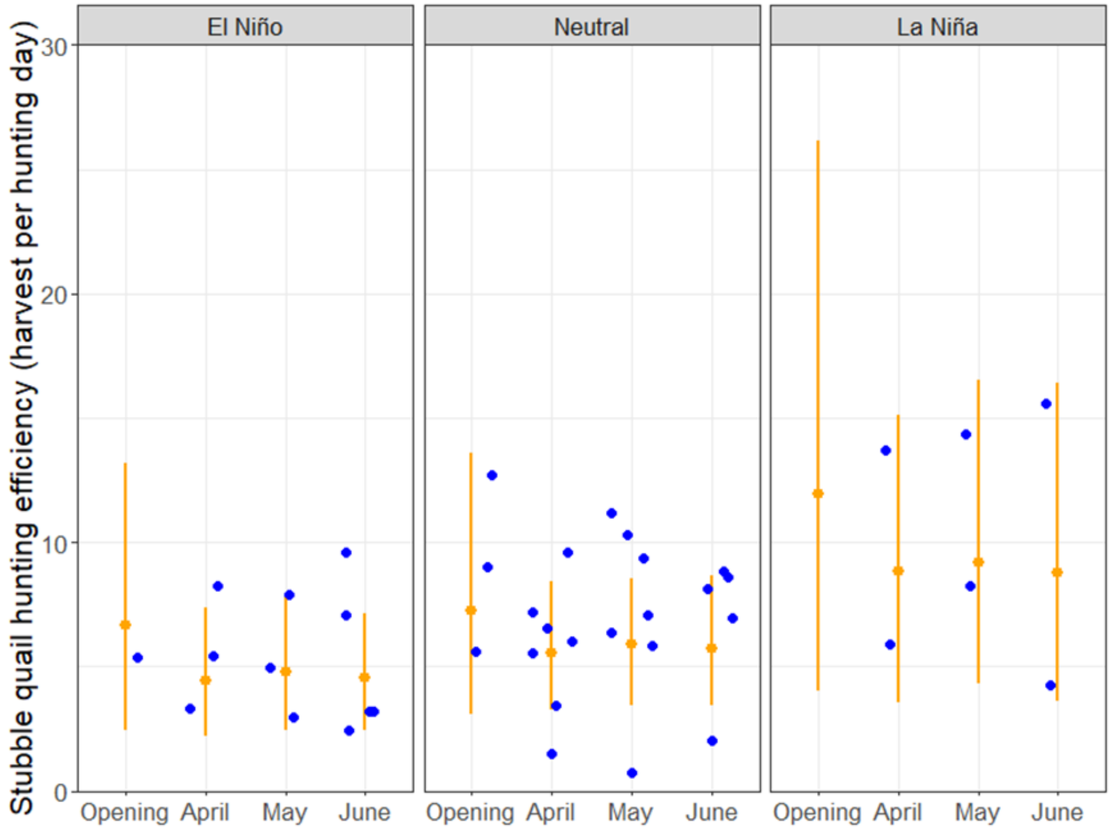


Fig. S4. Fitted model estimates for stubble quail hunting efficiency in Victoria, Australia, under the different environmental conditions observed from 2009−2019. The blue points are the point estimates from each hunter survey arranged in chronological order from left to right. The orange points are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



Code S1. JAGS code for deer model

```
DeerModelT <- function(){
  # Priors
  for(i in 1:6){
    alphaH[i] ~ dunif(-10, 10)
    alphaD[i] ~ dunif(-10, 10)
    alphaL[i] ~ dunif(-10, 10)
    gamma[i] ~ dunif(-10, 10)
  }
  for(i in 1:1){
    betaH[i] ~ dunif(-10, 10)
    betaD[i] ~ dunif(-10, 10)
    betaL[i] ~ dunif(-10, 10)
    delta[i] ~ dunif(-10, 10)
  }
  betaL[2] ~ dunif(-10, 10)
  for(i in 1:nSurvey){
    epsH[i] ~ dnorm(0, tauH)
    epsT[i] ~ dnorm(0, tauT)
    epsD[i] ~ dnorm(0, tauD)
    # epsL[i] ~ dnorm(0, tauL)
  }
  ## Random effects
  sL ~ dgamma(0.0001, 0.0001)
  tauL <- pow(sL, -2)
```

```
  sT ~ dgamma(0.0001, 0.0001)
  tauT <- pow(sT, -2)
  sH ~ dgamma(0.0001, 0.0001)
  tauH <- pow(sH, -2)
  sD ~ dgamma(0.0001, 0.0001)
  tauD <- pow(sD, -2)
  # Likelihoods
  for(i in 1:nSurvey){
    # Licences
    nLic[i] ~ dnorm(predL[i], tauL)
    log(predL[i]) <- alphaL[Survey[i]] + betaL[1]*Year[i] + betaL[2]*Year[i]*Year[i] +
log(1000)
    log(ExpL[i]) <- mean(alphaL[1:6]) + betaL[1]*Year[i] + betaL[2]*Year[i]*Year[i] +
log(1000) #Expected deseasoned Licences at a survey
    # Active hunters
    Hunters[i] ~ dbin(pHunt[i], Resp[i])
    logit(pHunt[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + epsT[i]
    # Harvest
    Harv[i] ~ dpois(HpAH[i]*Hunters[i])
    log(HpAH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + epsH[i]
    # Hunting days
    DpAH[i] <- lambda[i]*exp(lambda[i])/(exp(lambda[i]) - 1)
    log(lambda[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + epsD[i]
    ## Zeroes trick
    z[i] ~ dpois(phi[i])
```

```
    phi[i] <- logfact(Days[i]) + Hunters[i]*log(exp(lambda[i])-1) - Days[i]*log(lambda[i]) - log(LL[i])
    LL[i] <- sum(SS[i, 1:(Hunters[i] + 1)])
    for(j in 0:Hunters[i]){
      SS[i, j + 1] <- pow(-1, j)*pow(Hunters[i] - j, Days[i])*exp(logfact(Hunters[i]) - (logfact(j) + logfact(Hunters[i]) - j))
    }
    for(j in (Hunters[i] +1):MaxHunt){
      SS[i, j + 1] <- 0
    }
    # Derived statistics
    THunt[i] <- pHunt[i]*nLic[i] # Total active hunters per survey
    THarv[i] <- HpAH[i]*THunt[i] # Total harvest per survey
    TDays[i] <- DpAH[i]*THunt[i] # Total hunting days per survey
    HpL[i] <- THarv[i]/nLic[i] # Harvest per licence per survey
    DpL[i] <- TDays[i]/nLic[i] # Hunting days per licence per survey
    HpD[i] <- THarv[i]/TDays[i] # Harvest per day per survey
    logit(ExpP[i]) <- gamma[Survey[i]] + delta[1]*Time[i] # Expected proportion active hunters per survey
    ExpHunt[i] <- ExpP[i]*nLic[i] # Expected number of active hunters per survey
    log(ExpHpH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] # Expected harvest per active hunter per survey
    ExpHarv[i] <- ExpHpH[i]*ExpHunt[i] # Expected harvest per survey
    ExpHpL[i] <- ExpHpH[i]*ExpP[i] # Expected harvest per licence holder per survey
```

```
    log(ExpHpHnS[i]) <- mean(alphaH[1:6]) + betaH[1]*Time[i] # Expected deseasoned harvest per active hunter per survey
    ExpHarvnS[i] <- ExpHpHnS[i]*ExpHunt[i] # Expected deseasoned harvest per survey
    log(Explam[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] # Expected lambda hunting days per active hunter per survey
    ExpDpH[i] <- Explam[i]*exp(Explam[i])/(exp(Explam[i]) - 1) # Expected hunting days per active hunter per survey
    ExpDays[i] <- ExpDpH[i]*ExpHunt[i] # Expected hunting days per survey
    ExpDpL[i] <- ExpDpH[i]*ExpP[i] # Expected hunting days per licence holder per survey
    log(ExplamnS[i]) <- mean(alphaD[1:6]) + betaD[1]*Time[i] # Expected lambda deseasoned hunting days per active hunter per survey
    ExpDpHnS[i] <- ExplamnS[i]*exp(ExplamnS[i])/(exp(ExplamnS[i]) - 1) # Expected deseasoned hunting days per active hunter per survey
    ExpDaysnS[i] <- ExpDpHnS[i]*ExpHunt[i] # Expected deseasoned hunting days per survey
    ExpHpD[i] <- ExpHpH[i]/ExpDpH[i] # Expected efficency
    ExpHpDnS[i] <- ExpHpHnS[i]/ExpDpHnS[i] # Expected deseasoned efficency
  }
  # Yearly totals
  for(j in 1:nYears){
    TTHarv[j] <- sum(THarv[1:6 + 6*(j-1)])
    TTDays[j] <- sum(TDays[1:6 + 6*(j-1)])
    THpL[j] <- sum(HpL[1:6 + 6*(j-1)])
    TDpL[j] <- sum(DpL[1:6 + 6*(j-1)])
    THpD[j] <- THpL[j]/TDpL[j]
```

```
    TExpHarv[j] <- sum(ExpHarv[1:6 + 6*(j-1)])
    TExpDays[j] <- sum(ExpDays[1:6 + 6*(j-1)])
    TExpHpL[j] <- sum(ExpHpL[1:6 + 6*(j-1)])
    TExpDpL[j] <- sum(ExpDpL[1:6 + 6*(j-1)])
    TExpHpD[j] <- TExpHpL[j]/TExpDpL[j]
  }
  # Average growth
  HarvGrowSurv <- exp(mean(log(ExpHarv[2:nSurvey]/ExpHarv[1:(nSurvey-1)])))
  HarvGrowYear <- exp(mean(log(TExpHarv[2:nYears]/TExpHarv[1:(nYears-1)])))
}
```

Code S2. JAGS code for duck model

```
DuckModelT <- function(){
  # Priors
  for(i in 1:5){
    alphaH[i] ~ dunif(-10, 10)
    alphaD[i] ~ dunif(-10, 10)
    alphaL[i] ~ dunif(-10, 10)
    gamma[i] ~ dunif(-10, 10)
  }
  for(i in 1:5){
    betaH[i] ~ dunif(-10, 10)
    betaD[i] ~ dunif(-10, 10)
    betaL[i] ~ dunif(-10, 10)
    delta[i] ~ dunif(-10, 10)
  }
  for(i in 1:nSurvey){
    epsH[i] ~ dnorm(0, tauH)
    epsT[i] ~ dnorm(0, tauT)
    epsD[i] ~ dnorm(0, tauD)
    # epsL[i] ~ dnorm(0, tauL)
  }
  # for(i in 1:nYears){
  #   epsLY[i] ~ dnorm(0, tauLY)
  # }
  ## Random effects
```

```
 sL ~ dgamma(0.0001, 0.0001)
 tauL <- pow(sL, -2)
 sT ~ dgamma(0.0001, 0.0001)
 tauT <- pow(sT, -2)
 sH ~ dgamma(0.0001, 0.0001)
 tauH <- pow(sH, -2)
 sD ~ dgamma(0.0001, 0.0001)
 tauD <- pow(sD, -2)
 # Likelihoods
 for(i in 1:nmYear){
   # Licences
   mLic[i] ~ dnorm(predL[i], tauL)
   log(predL[i]) <- alphaL[mMonth[i]] + betaL[2]*mYear[i] + betaL[3]*mYear[i]*mYear[i] + betaL[4]*mRedBag[i] + log(1000)
   log(ExpL[i]) <- mean(alphaL[1:4]) + betaL[2]*mYear[i] + betaL[3]*mYear[i]*mYear[i] + betaL[4]*mRedBag[i] + log(1000) # Expected deseasoned Licences at a survey
 }
 for(i in 1:nSurvey){
   # Active hunters
   Hunters[i] ~ dbin(pHunt[i], Resp[i])
   logit(pHunt[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + delta[2]*ElNino[i] + delta[3]*LaNina[i] + delta[4]*RedBag[i] + delta[5]*ElNino[i]*RedBag[i] + epsT[i]
   # Harvest
   Harv[i] ~ dpois(HpAH[i]*Hunters[i])
```

```
log(HpAH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] + betaH[3]*LaNina[i] + betaH[4]*RedBag[i] + betaH[5]*ElNino[i]*RedBag[i] + epsH[i]
# Hunting days
DpAH[i] <- lambda[i]*exp(lambda[i])/(exp(lambda[i]) - 1)
log(lambda[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] + betaD[3]*LaNina[i] + betaD[4]*RedBag[i] + betaD[5]*ElNino[i]*RedBag[i] + epsD[i]
## Zeroes trick
z[i] ~ dpois(phi[i])
phi[i] <- logfact(Days[i]) + Hunters[i]*log(exp(lambda[i])-1) - Days[i]*log(lambda[i]) - log(LL[i]) + 10000
LL[i] <- sum(SS[i, 1:(Hunters[i] + 1)])
for(j in 0:Hunters[i]){
  SS[i, j + 1] <- pow(-1, j)*pow(Hunters[i] - j, Days[i])*exp(logfact(Hunters[i]) - (logfact(j) + logfact(Hunters[i]) - j))
}
for(j in (Hunters[i] +1):MaxHunt){
  SS[i, j + 1] <- 0
}
# Derived statistics
THunt[i] <- pHunt[i]*nLic[i] # Total active hunters per survey
THarv[i] <- HpAH[i]*THunt[i] # Total harvest per survey
TDays[i] <- DpAH[i]*THunt[i] # Total hunting days per survey
HpL[i] <- THarv[i]/nLic[i] # Harvest per licence per survey
DpL[i] <- TDays[i]/nLic[i] # Hunting days per licence per survey
HpD[i] <- THarv[i]/TDays[i] # Harvest per day per survey
```

```
    logit(ExpP[i]) <- gamma[Survey[i]] + delta[1]*Time[i]  + delta[2]*ElNino[i] + delta[3]*LaNina[i] + delta[4]*RedBag[i] + delta[5]*ElNino[i]*RedBag[i]# Expected proportion active hunters per survey
    ExpHunt[i] <- ExpP[i]*nLic[i] # Expected number of active hunters per survey
    log(ExpHpH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] + betaH[3]*LaNina[i] + betaH[4]*RedBag[i] + betaH[5]*ElNino[i]*RedBag[i] # Expected harvest per active hunter per survey
    ExpHarv[i] <- ExpHpH[i]*ExpHunt[i] # Expected harvest per survey
    ExpHpL[i] <- ExpHpH[i]*ExpP[i] # Expected harvest per licence holder per survey
    log(ExpHpHnS[i]) <- mean(alphaH[1:5]) + betaH[1]*Time[i]  + betaH[2]*ElNino[i] + betaH[3]*LaNina[i] + betaH[4]*RedBag[i] + betaH[5]*ElNino[i]*RedBag[i]# Expected deseasoned harvest per active hunter per survey
    ExpHarvnS[i] <- ExpHpHnS[i]*ExpHunt[i] # Expected deseasoned harvest per survey
    log(Explam[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] + betaD[3]*LaNina[i] + betaD[4]*RedBag[i] + betaD[5]*ElNino[i]*RedBag[i] # Expected lambda hunting days per active hunter per survey
    ExpDpH[i] <- Explam[i]*exp(Explam[i])/(exp(Explam[i]) - 1) # Expected hunting days per active hunter per survey
    ExpDays[i] <- ExpDpH[i]*ExpHunt[i] # Expected hunting days per survey
    ExpDpL[i] <- ExpDpH[i]*ExpP[i] # Expected hunting days per licence holder per survey
    log(ExplamnS[i]) <- mean(alphaD[1:5]) + betaD[1]*Time[i] + betaD[2]*ElNino[i] + betaD[3]*LaNina[i] + betaD[4]*RedBag[i] + betaD[5]*ElNino[i]*RedBag[i] # Expected lambda deseasoned hunting days per active hunter per survey
    ExpDpHnS[i] <- ExplamnS[i]*exp(ExplamnS[i])/(exp(ExplamnS[i]) - 1)# Expected deseasoned hunting days per active hunter per survey
```

```
    ExpDaysnS[i] <- ExpDpHnS[i]*ExpHunt[i] # Expected deseasoned hunting days per survey
    ExpHpD[i] <- ExpHpH[i]/ExpDpH[i] # Expected efficency
    ExpHpDnS[i] <- ExpHpHnS[i]/ExpDpHnS[i] # Expected deseasoned efficency
  }
  # Yearly totals
  for(j in 1:nYears){
    TTHarv[j] <- sum(THarv[SurvStart[j]:SurvEnd[j]])
    TTDays[j] <- sum(TDays[SurvStart[j]:SurvEnd[j]])
    THpL[j] <- sum(HpL[SurvStart[j]:SurvEnd[j]])
    TDpL[j] <- sum(DpL[SurvStart[j]:SurvEnd[j]])
    THpD[j] <- THpL[j]/TDpL[j]
    TExpHarv[j] <- sum(ExpHarv[SurvStart[j]:SurvEnd[j]])
    TExpDays[j] <- sum(ExpDays[SurvStart[j]:SurvEnd[j]])
    TExpHpL[j] <- sum(ExpHpL[SurvStart[j]:SurvEnd[j]])
    TExpDpL[j] <- sum(ExpDpL[SurvStart[j]:SurvEnd[j]])
    TExpHpD[j] <- TExpHpL[j]/TExpDpL[j]
  }
  # Average growth
  HarvGrowSurv <- exp(mean(log(ExpHarv[2:nSurvey]/ExpHarv[1:(nSurvey-1)])))
  HarvGrowYear <- exp(mean(log(TExpHarv[2:nYears]/TExpHarv[1:(nYears-1)])))
  EffGrowYear <- exp(mean(log(TExpHpD[2:nYears]/TExpHpD[1:(nYears-1)])))
}
```

Code S3. JAGS code for quail model

```
QuailModelT <- function(){
  # Priors
  for(i in 1:4){
    alphaH[i] ~ dunif(-10, 10)
    alphaD[i] ~ dunif(-10, 10)
    alphaL[i] ~ dunif(-10, 10)
    gamma[i] ~ dunif(-10, 10)
  }
  for(i in 1:3){
    betaH[i] ~ dunif(-10, 10)
    betaD[i] ~ dunif(-10, 10)
    betaL[i] ~ dunif(-10, 10)
    delta[i] ~ dunif(-10, 10)
  }
  for(i in 1:nSurvey){
    epsH[i] ~ dnorm(0, tauH)
    epsT[i] ~ dnorm(0, tauT)
    epsD[i] ~ dnorm(0, tauD)
    # epsL[i] ~ dnorm(0, tauL)
  }
  # for(i in 1:nYears){
  #   epsLY[i] ~ dnorm(0, tauLY)
  # }
  ## Random effects
```

```
  sL ~ dgamma(0.0001, 0.0001)
  tauL <- pow(sL, -2)
  sT ~ dgamma(0.0001, 0.0001)
  tauT <- pow(sT, -2)
  sH ~ dgamma(0.0001, 0.0001)
  tauH <- pow(sH, -2)
  sD ~ dgamma(0.0001, 0.0001)
  tauD <- pow(sD, -2)
  # Likelihoods
  for(i in 1:nmYear){
    # Licences
    mLic[i] ~ dnorm(predL[i], tauL)
    log(predL[i]) <- alphaL[mMonth[i]] + betaL[1]*mYear[i] + betaL[2]*mYear[i]*mYear[i] + log(1000)
    log(ExpL[i]) <- mean(alphaL[1:3]) + betaL[1]*mYear[i] + betaL[2]*mYear[i]*mYear[i] + log(1000) # Expected deseasoned Licences at a survey
  }
  for(i in 1:nSurvey){
    # Active hunters
    Hunters[i] ~ dbin(pHunt[i], Resp[i])
    logit(pHunt[i]) <- gamma[Survey[i]] + delta[1]*Time[i] + delta[2]*ElNino[i] + delta[3]*LaNina[i] + epsT[i]
    # Harvest
    Harv[i] ~ dpois(HpAH[i]*Hunters[i])
```

```
    log(HpAH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] +
betaH[3]*LaNina[i] + epsH[i]
    # Hunting days
    DpAH[i] <- lambda[i]*exp(lambda[i])/(exp(lambda[i]) - 1)
    log(lambda[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] +
betaD[3]*LaNina[i] + epsD[i]
    ## Zeroes trick
    z[i] ~ dpois(phi[i])
    phi[i] <- logfact(Days[i]) + Hunters[i]*log(exp(lambda[i])-1) - Days[i]*log(lambda[i]) -
log(LL[i]) + 100000
    LL[i] <- sum(SS[i, 1:(Hunters[i] + 1)])
    for(j in 0:Hunters[i]){
      SS[i, j + 1] <- pow(-1, j)*pow(Hunters[i] - j, Days[i])*exp(logfact(Hunters[i]) -
(logfact(j) + logfact(Hunters[i]) - j))
    }
    for(j in (Hunters[i] +1):MaxHunt){
      SS[i, j + 1] <- 0
    }
    # Derived statistics
    THunt[i] <- pHunt[i]*nLic[i] # Total active hunters per survey
    THarv[i] <- HpAH[i]*THunt[i] # Total harvest per survey
    TDays[i] <- DpAH[i]*THunt[i] # Total hunting days per survey
    HpL[i] <- THarv[i]/nLic[i] # Harvest per licence per survey
    DpL[i] <- TDays[i]/nLic[i] # Hunting days per licence per survey
    HpD[i] <- THarv[i]/TDays[i] # Harvest per day per survey
```

```
    logit(ExpP[i]) <- gamma[Survey[i]] + delta[1]*Time[i]  + delta[2]*ElNino[i] + delta[3]*LaNina[i]# Expected proportion active hunters per survey
    ExpHunt[i] <- ExpP[i]*nLic[i] # Expected number of active hunters per survey
    log(ExpHpH[i]) <- alphaH[Survey[i]] + betaH[1]*Time[i] + betaH[2]*ElNino[i] + betaH[3]*LaNina[i]# Expected harvest per active hunter per survey
    ExpHarv[i] <- ExpHpH[i]*ExpHunt[i] # Expected harvest per survey
    ExpHpL[i] <- ExpHpH[i]*ExpP[i] # Expected harvest per licence holder per survey
    log(ExpHpHnS[i]) <- mean(alphaH[1:4]) + betaH[1]*Time[i]  + betaH[2]*ElNino[i] + betaH[3]*LaNina[i]# Expected deseasoned harvest per active hunter per survey
    ExpHarvnS[i] <- ExpHpHnS[i]*ExpHunt[i] # Expected deseasoned harvest per survey
    log(Explam[i]) <- alphaD[Survey[i]] + betaD[1]*Time[i] + betaD[2]*ElNino[i] + betaD[3]*LaNina[i]# Expected lambda hunting days per active hunter per survey
    ExpDpH[i] <- Explam[i]*exp(Explam[i])/(exp(Explam[i]) - 1) # Expected hunting days per active hunter per survey
    ExpDays[i] <- ExpDpH[i]*ExpHunt[i] # Expected hunting days per survey
    ExpDpL[i] <- ExpDpH[i]*ExpP[i] # Expected hunting days per licence holder per survey
    log(ExplamnS[i]) <- mean(alphaD[1:4]) + betaD[1]*Time[i] + betaD[2]*ElNino[i] + betaD[3]*LaNina[i]# Expected lambda deseasoned hunting days per active hunter per survey
    ExpDpHnS[i] <- ExplamnS[i]*exp(ExplamnS[i])/(exp(ExplamnS[i]) - 1)# Expected deseasoned hunting days per active hunter per survey
    ExpDaysnS[i] <- ExpDpHnS[i]*ExpHunt[i] # Expected deseasoned hunting days per survey
    ExpHpD[i] <- ExpHpH[i]/ExpDpH[i] # Expected efficency
    ExpHpDnS[i] <- ExpHpHnS[i]/ExpDpHnS[i] # Expected deseasoned efficency
  }
```

```
  # Yearly totals
  for(j in 1:nYears){
    TTHarv[j] <- sum(THarv[SurvStart[j]:SurvEnd[j]])
    TTDays[j] <- sum(TDays[SurvStart[j]:SurvEnd[j]])
    THpL[j] <- sum(HpL[SurvStart[j]:SurvEnd[j]])
    TDpL[j] <- sum(DpL[SurvStart[j]:SurvEnd[j]])
    THpD[j] <- THpL[j]/TDpL[j]
    TExpHarv[j] <- sum(ExpHarv[SurvStart[j]:SurvEnd[j]])
    TExpDays[j] <- sum(ExpDays[SurvStart[j]:SurvEnd[j]])
    TExpHpL[j] <- sum(ExpHpL[SurvStart[j]:SurvEnd[j]])
    TExpDpL[j] <- sum(ExpDpL[SurvStart[j]:SurvEnd[j]])
    TExpHpD[j] <- TExpHpL[j]/TExpDpL[j]
  }
  # Average growth
  HarvGrowSurv <- exp(mean(log(ExpHarv[2:nSurvey]/ExpHarv[1:(nSurvey-1)])))
  HarvGrowYear <- exp(mean(log(TExpHarv[2:nYears]/TExpHarv[1:(nYears-1)])))
  EffGrowYear <- exp(mean(log(TExpHpD[2:nYears]/TExpHpD[1:(nYears-1)])))
}
```