**APPENDIX 4**

Listing of WinBUGS code for the trend analyses of radar counts of Marbled Murrelets in British Columbia.

#Model 33g\_8, March 6, 2019, developed by Murdoch McAllister

model{

#March. 12, 2019

#all regions included

#change between observed yrs accounts for # yrs bet. obs.

#hierarchical regression model predicting pre-dawn radar counts

# slope and intercept are treated as hierarchical

#Year covariate is mean centered (X-Xbar)

#Reduced set of year effects estimated

#precision is estimated by region

#DOY effect different across regions and setting the constant at zero

#variance in year effect estimated - using DOY unadjusted - 182

#estimating DOYC by region as adjustment from 182 centre point

#prior mean for SD in year effect set at 10

#DOYA prior set over zero and negative values

#DOYA set to be the same between regions

#tilt treated as a covariate

#tauc<-1/(30\*30) increased sd from 10 to 30

#uses same year effects as base case from 2014

#Central Coast 2008 year effect estimated

#EVI 2018 year effect estimated

#max put on initial count component and min put on year effect

#Negative Binomial Distribution for likelihood function

#New estimate of standardized average annual count by region

#evaluate the probability of each observed radar count given the model

for (i in 1:1014){

# Obs\_Predawn[i]~dlnorm(lpredD[i], precD[Region[i]])

# lpredD[i]<-log(predD[i])

 Obs\_Predawn[i]~dpois(predD[i])

 predD[i]<- max(predDx[i],0)\*rx[i]

 rx[i]~dgamma(kpar[Site[i]],kpar[Site[i]])

#predict the pred-dawn count given the year, etc.

 **predDx[i]<-bcount[i]\*(1+Year\_effect[Year\_ind[i]])\*DOYE[i]\*(1+Tilt\_effect\*Tilt[i])**

 **bcount[i] <- max(1,(intercept[Site[i]]+slope[Site[i]]\*(Year[i]-Mean\_Year[i])))**

 **#predict the day of year effect by region**

 **DOYE[i]<- 1+ DOYA\*(DOY[i]+DOYC[Region[i]])\*(DOY[i]+DOYC[Region[i]])**

}

#Predict the count for the 1st yr for site #1

 DOYS <- 10 #determine a standard DOY

 predD\_P[1]<- max(predD\_Px[1],1)

 **predD\_Px[1]<-(intercept[Sited[1]]+slope[Sited[1]]\*(Yeard[1]-Mean\_yeard[1]))\*(1+Year\_effect[Yearc[1]])\*(1+Tilt\_effect\*25) \* DOYEP[1]**

**#compute DOY effect**

**DOYEP[1]<- 1+ DOYA\*(**DOYS**+DOYC[Regiond[1]])\*(**DOYS**+DOYC[Regiond[1]])**

delta\_s[1] <- 0

#Predict the count for each observed yr for each site

for (i in 2:291){

 predD\_P[i]<- max(predD\_Px[i],1)

 **predD\_Px[i]<-(intercept[Sited[i]]+slope[Sited[i]]\*(Yeard[i]-Mean\_yeard[i]))\*(1+Year\_effect[Yearc[i]])\*(1+Tilt\_effect\*25) \* DOYEP[i]**

**#compute DOY effect**

 **DOYEP[i]<- 1+ DOYA\*(**DOYS**+DOYC[Regiond[i]])\*(**DOYS**+DOYC[Regiond[i]])**

**#compute the per year relative change in abund. bet. ea. successive observed time**

 delta\_s[i] <- **(predD\_P[i] - predD\_P[i-1])/ (predD\_P[i-1]\*(Yeard[i]-Yeard[i-1]))**

}

#compute province wide mean annual change in count

 delta\_s\_all <- mean(delta\_s\_av[1:58])

#compute probability that there is a province wide decline

 P\_value\_all <- 1- step(delta\_s\_all)

tauc<-1/(30\*30)

DOYA~dunif(-0.02,0) # dnorm(0,taua)

DOYA\_prior~dunif(-0.02,0) #~dnorm(0,taua)

#formulate priors by region

for (i in 1:6){

 # DOYC[i]<- 0 #-DOYCp[i] # the constant in the 2nd O polynomial is set to zero

 DOYC[i]~dnorm(0,tauc)

 DOYC\_prior[i]~dnorm(0,tauc)

 #precD[i]~dgamma(0.01,0.01) #prior on the precision in the data

 #SE[i] <- 1/ sqrt(precD[i])

 **#compute probability of decline in each region**

 #method #1

 pval\_delta\_Ra[i] <- 1-step(delta\_Rava[i])

 #method #2

 delta\_Ravb[i] <- mean(delta\_s\_av[minReg[i]:maxReg[i]]**)**

 pval\_delta\_Rb[i] <- 1-step(delta\_Ravb[i])

 Pvalue\_rateR[i] <- 1-step(murateR[i]) #calc prob of a decrease

 muslopeRR[i]<- murateR[i] \* muinterceptR[i]

}

#prior put on sd in year effects

Year\_medSD < - 10

lYear\_medSD<- log(Year\_medSD)

tau\_Year<- 1/ (0.8\*0.8)

Year\_SD~dlnorm(lYear\_medSD, tau\_Year)

Year\_SDp~dlnorm(lYear\_medSD, tau\_Year)

Year\_tau<- 1/ (Year\_SD\*Year\_SD)

#Determine year effect priors

#Central Coast

Year\_effect[1]<-0 #~dnorm(0,Year\_tau) #1998

Year\_effect[2]<-0 #~dnorm(0,Year\_tau) #2006

Year\_effect[3]~dnorm(0,Year\_tau)I(-1,) #2008

Year\_effect[4]<-0 #2017

#East VI

for (i in 5:7){ #2003-2005

 Year\_effect[i]~dnorm(0,Year\_tau)I(-1,)

}

Year\_effect[8]<-0 #OK 2006

for (i in 9:15){ #2007-2008,2010-2013, 2018

 Year\_effect[i]~dnorm(0,Year\_tau)I(-1,)

}

#West Coast

Year\_effect[16]~dnorm(0,Year\_tau)I(-1,) #1996

for (i in 17:25){ #1997-1999, 2001-2006

 Year\_effect[i]~dnorm(0,Year\_tau)I(-1,)

}

Year\_effect[26]<-0 #2007

for (i in 27:33){ #2008-2013, 2016

 Year\_effect[i]~dnorm(0,Year\_tau)I(-1,)

}

Year\_effect[34]<-0 #2018

#Haida Gwai

for (i in 35:38){ #2003-2007

 Year\_effect[i]<-0

}

Year\_effect[39]~dnorm(0,Year\_tau)I(-1,) **#2010**

Year\_effect[40]<-0

#North Coast

for (i in 41:42){ #1998, 2001

 Year\_effect[i]<-0

}

Year\_effect[43]~dnorm(0,Year\_tau)I(-1,) #2005

for (i in 44:45){ #2009, 2014

Year\_effect[i]<-0

}

#South Coast

Year\_effect[46]<-0 #2000

for (i in 47:48){ #2001, 2006

 Year\_effect[i]~dnorm(0,Year\_tau)I(-1,)

}

Year\_effect[49]<-0 #2008

Year\_effect[50]~dnorm(0,Year\_tau)I(-1,) #2010

Year\_effect[51]<-0 #2015

#predict region wide count in each year

#Central Coast 1-4

 predD\_R[1]<- max(predD\_Rx[1],1)

 **predD\_Rx[1]<-(**muinterceptR[1]**+**muslopeRR[1]**\*(YearR[1]-MeanYR[1]))\*(1+Year\_effect[1])\*(1+Tilt\_effect\*25)\*DOYER[1]**

**DOYER[1]<- 1+ DOYA\*(**DOYS**+DOYC[1])\*(**DOYS**+DOYC[1])**

 **delta\_R[1] <- 0**

 for (i in 2: 4) {

 predD\_R[i]<- max(predD\_Rx[i],1)

 **predD\_Rx[i]<-(**muinterceptR[1]**+**muslopeRR[1]**\*(YearR[i]-MeanYR[1]))\*(1+Year\_effect[i])\*(1+Tilt\_effect\*25)\*DOYER[1]**

 **delta\_R[i] <- (predD\_R[i] - predD\_R[i-1]) / (predD\_R[i-1] \* (YearR[i]-YearR[i-1]))**

 }

 delta\_Rava[1] <- mean(**delta\_R[2:4]) #calc the average rate of change by region**

#East Vancouver Island 5-15

 predD\_R[5]<- max(predD\_Rx[5],1)

 **predD\_Rx[5]<-(**muinterceptR[2]**+**muslopeRR[2]**\*(YearR[5]-MeanYR[2]))\*(1+Year\_effect[5])\*(1+Tilt\_effect\*25)\*DOYER[2]**

**DOYER[2]<- 1+ DOYA\*(**DOYS**+DOYC[2])\*(**DOYS**+DOYC[2])**

 for (i in 6: 15) {

 predD\_R[i]<- max(predD\_Rx[i],1)

 **predD\_Rx[i]<-(**muinterceptR[2]**+**muslopeRR[2]**\*(YearR[i]-MeanYR[2]))\*(1+Year\_effect[i])\*(1+Tilt\_effect\*25)\*DOYER[2]**

 **delta\_R[i] <- (predD\_R[i] - predD\_R[i-1]) /(predD\_R[i-1] \* (YearR[i]-YearR[i-1]))**

 }

 delta\_Rava[2] <- mean(**delta\_R[6:15])**

#West coast 16-34

 predD\_R[16]<- max(predD\_Rx[16],1)

 **predD\_Rx[16]<-(**muinterceptR[3]**+**muslopeRR[3]**\*(YearR[16]-MeanYR[3]))\*(1+Year\_effect[16])\*(1+Tilt\_effect\*25)\*DOYER[3]**

**DOYER[3]<- 1+ DOYA\*(**DOYS**+DOYC[3])\*(**DOYS**+DOYC[3])**

 for (i in 17: 34) {

 predD\_R[i]<- max(predD\_Rx[i],1)

 **predD\_Rx[i]<-(**muinterceptR[3]**+**muslopeRR[3]**\*(YearR[i]-MeanYR[3]))\*(1+Year\_effect[i])\*(1+Tilt\_effect\*25)\*DOYER[3]**

 **delta\_R[i] <- (predD\_R[i] - predD\_R[i-1]) / (predD\_R[i-1] \* (YearR[i]-YearR[i-1]))**

 }

 delta\_Rava[3] <- mean(**delta\_R[17:34])**

#Haida Gwai 35-40

 predD\_R[35]<- max(predD\_Rx[35],1)

**predD\_Rx[35]<-(**muinterceptR[4]**+**muslopeRR[4]**\*(YearR[35]-MeanYR[4]))\*(1+Year\_effect[35])\*(1+Tilt\_effect\*25)\*DOYER[4]**

**DOYER[4]<- 1+ DOYA\*(**DOYS**+DOYC[4])\*(**DOYS**+DOYC[4])**

 for (i in 36: 40) {

 predD\_R[i]<- max(predD\_Rx[i],1)

 **predD\_Rx[i]<-(**muinterceptR[4]**+**muslopeRR[4]**\*(YearR[i]-MeanYR[4]))\*(1+Year\_effect[i])\*(1+Tilt\_effect\*25)\*DOYER[4]**

 **delta\_R[i] <- (predD\_R[i] - predD\_R[i-1]) /(predD\_R[i-1] \* (YearR[i]-YearR[i-1]))**

 }

 delta\_Rava[4] <- mean(**delta\_R[36:40])**

#North coast 41-45

 predD\_R[41]<- max(predD\_Rx[41],1)

**predD\_Rx[41]<-(**muinterceptR[5]**+**muslopeRR[5]**\*(YearR[41]-MeanYR[5]))\*(1+Year\_effect[41])\*(1+Tilt\_effect\*25)\*DOYER[5]**

**DOYER[5]<- 1+ DOYA\*(**DOYS**+DOYC[5])\*(**DOYS**+DOYC[5])**

 for (i in 42: 45) {

 predD\_R[i]<- max(predD\_Rx[i],1)

 **predD\_Rx[i]<-(**muinterceptR[5]**+**muslopeRR[5]**\*(YearR[i]-MeanYR[5]))\*(1+Year\_effect[i])\*(1+Tilt\_effect\*25)\*DOYER[5]**

 **delta\_R[i] <- (predD\_R[i] - predD\_R[i-1]) /(predD\_R[i-1] \* (YearR[i]-YearR[i-1]))**

 }

 delta\_Rava[5] <- mean(**delta\_R[42:45])**

#South coast 46-51

 predD\_R[46]<- max(predD\_Rx[46],1)

**predD\_Rx[46]<-(**muinterceptR[6]**+**muslopeRR[6]**\*(YearR[46]-MeanYR[6]))\*(1+Year\_effect[46])\*(1+Tilt\_effect\*25)\*DOYER[6]**

**DOYER[6]<- 1+ DOYA\*(**DOYS**+DOYC[6])\*(**DOYS**+DOYC[6])**

 for (i in 47: 51) {

 predD\_R[i]<- max(predD\_Rx[i],1)

 **predD\_Rx[i]<-(**muinterceptR[6]**+**muslopeRR[6]**\*(YearR[i]-MeanYR[6]))\*(1+Year\_effect[i])\*(1+Tilt\_effect\*25)\*DOYER[6]**

 **delta\_R[i] <- (predD\_R[i] - predD\_R[i-1]) / (predD\_R[i-1] \* (YearR[i]-YearR[i-1]))**

 }

delta\_Rava[6] <- mean(**delta\_R[47:51])**

muhslope~dnorm(0,0.0001) #hyper prior for mean of slopes

muhslopep~dnorm(0,0.0001) #hyper prior for mean of slopes

tauhslope<- 1/(sdhslope\*sdhslope) #computation of prior prec. in slope

sdhslope~dlnorm(lsdh\_mu,tau\_sdh) #hyper prior for sd of slopes

sdhslopep~dlnorm(lsdh\_mu,tau\_sdh) #hyper prior for sd of slopes

sdh\_mu<-10

lsdh\_mu<-log(sdh\_mu)

sdh\_sd<-0.8

tau\_sdh<- 1/(sdh\_sd\*sdh\_sd)

#slope to be treated as a hierarchical parameter across sites

for (i in 1:58){

 slope[i]~dnorm(muhslope,tauhslope)

 intercept[i]~dlnorm(lmedinterc,tauint)

 rate[i]<-slope[i]/intercept[i]

 Pvalue\_rate[i] <- 1-step(rate[i]) #calc prob of a decrease

#calc. the average rate of change per site.

 delta\_s\_av[i] <- mean(delta\_s[minSite[i]: maxSite[i]])

#calc. prob. of decline in each site

 P\_value\_delta\_s[i] <- 1- step(delta\_s\_av[i])

}

#lmedinterc<-log(50)

#tauint<-1/(0.8\*0.8)

lmedinterc<-log(medinterc)

#medinterc~dlnorm(lmedintercp,tauintp) #hyperprior for prior med for intercept

#medintercp~dlnorm(lmedintercp,tauintp) #hyperprior for prior med for intercept

medinterc~dunif(1, 2000)

medintercp~dunif(1, 2000)

lmedintercp<-log(50)

tauintp<-1/(0.8\*0.8)

tauint<-1/(sdhintercept\*sdhintercept) #hyperprior for prior prec of intercept

sdhintercept~dlnorm(lsdinth\_mu,tau\_sdinth) #hyper prior for sd of intercept

sdhinterceptp~dlnorm(lsdinth\_mu,tau\_sdinth) #hyper prior for sd of intercepts

sdinth\_mu<-50 #should be centred at a much lower value, e.g., at 1

lsdinth\_mu<-log(sdinth\_mu)

sdinth\_sd<-0.8

tau\_sdinth<- 1/(sdinth\_sd\*sdinth\_sd)

#prior density for tilt effect

Tilt\_effect~dnorm(0,1)

Tilt\_effect\_prior~dnorm(0,1)

#calc. the averages for slopes and intercepts across sites and regions

muslopeR[1]<- mean(slope[1:10])

muslopeR[2]<-mean(slope[11:15])

muslopeR[3]<-mean(slope[16:27])

muslopeR[4]<- mean(slope[28:39])

muslopeR[5]<-mean(slope[40:48])

muslopeR[6]<-mean(slope[49:58])

muinterceptR[1]<- mean(intercept[1:10])

muinterceptR[2]<-mean(intercept[11:15])

muinterceptR[3]<-mean(intercept[16:27])

muinterceptR[4]<- mean(intercept[28:39])

muinterceptR[5]<-mean(intercept[40:48])

muinterceptR[6]<-mean(intercept[49:58])

murateR[1]<- mean(rate[1:10])

murateR[2]<-mean(rate[11:15])

murateR[3]<-mean(rate[16:27])

murateR[4]<- mean(rate[28:39])

murateR[5]<-mean(rate[40:48])

murateR[6]<-mean(rate[49:58])

#for (i in 1:6) {

#}

muslopep<- abs(muslope)

muratep<- abs(murate)

muslope<-mean(slope[]) #take mean of slopes across sites

sdslope<-sd(slope[]) #take sd of slope across sites

murate<-mean(rate[]) #take mean of rates across sites

Pvalue\_murate <- 1-step(murate)

sdrate<-sd(rate[]) #take sd of rate across sites

CVslope<-sdslope/muslopep

CVrate<-sdrate/muratep

muintercept<-mean(intercept[])

sdintercept<-sd(intercept[])

CVintercept<-sdintercept/muintercept

}

Appendix 2. Listing of the Script (Batch file code) to implement the base case model in the second round of analysis.

display(log)

#run with data from all six regions

#DOY different by region

#variance in year effect estimated - using DOY unadjusted

#both intercept and slope as hierarchical

#doyc prior has sd increased from 10 to 30

#year effects CC 2008 & EV 2018 estimated also

#Negative binomial likelihood function, iteration 4

#Use of new method to predict counts by region

check('birds\model\_nh\_v33g\_8.odc')

data('birds\data\_v31\_0\_1.odc')

data('birds\data\_v27a.odc')

data('birds\data\_v27b.odc')

data('birds\data\_v27c.odc')

data('birds\data\_v27d.odc')

data('birds\data\_v27e.odc')

data('birds\data\_v33i.odc')

compile(2)

inits(1, 'birds\in31g6\_1.odc')

inits(2, 'birds\in31g6\_2.odc')

gen.inits()

set(muslope)

set(CVslope)

set(murate)

set(CVrate)

set(muintercept)

set(CVintercept)

set(slope)

set(muslopeR)

set(muinterceptR)

set(murateR)

set(intercept)

set(Tilt\_effect)

#set(Tilt\_effect\_prior)

set(Year\_effect)

**set(predD\_R)**

**set(predD\_P)**

set(DOYA)

set(DOYC)

#set(DOYA\_prior)

#set(DOYC\_prior)

#set(SE)

set(Year\_SD)

set(Year\_SDp)

set(muhslope)

set(muhslopep)

set(sdhslope)

set(sdhslopep)

set(medinterc)

set(medintercp)

set(sdhintercept)

set(sdhinterceptp)

set(rate)

set(pval\_delta\_Ra)

set(pval\_delta\_Rb)

set(Pvalue\_rate)

set(Pvalue\_rateR)

set(Pvalue\_murate)

set(P\_value\_delta\_s)

set(P\_value\_all)

set(delta\_Rava)

set(delta\_Ravb)

set(delta\_s\_av)

set(delta\_s\_all)

refresh(1000) #1000

update(15000) #40000

beg(15001) #40001

dic.set()

#trace(slope)

update(60000) #80000

#autoC(slope)

#autoC(intercept)

#autoC(DOYA)

#autoC(DOYC)

#autoC(SE)

#autoC(Tilt\_effect)

#autoC(Year\_effect)

**#gr(slope)**

**#gr(intercept)**

**#gr(SE)**

**#gr(DOYC)**

**#gr(slope)**

**#gr(intercept)**

**#gr(Tilt\_effect)**

density(slope)

density(intercept)

density(DOYA)

density(DOYC)

#density(SE)

density(Tilt\_effect)

density(Year\_effect)

density(rate)

density(delta\_s\_av)

density(delta\_Rava)

density(delta\_Ravb)

density(delta\_s\_all)

stats(\*)

**dic.stats()**

**#thin.samples(100)**

**#coda(delta\_Ravb)**

**#coda(**delta\_s\_all)