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Reanalysis of Banks Peninsula Hector's dolphin demographic data

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EXECUTIVE SUMMARY

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Since 1984/85 (hereafter referred to by end year, i.e., 1985), University of Otago researchers have developed a photographic catalogue of Hector's dolphin (*Cephalorhynchus hectori*) sightings made inside the Banks Peninsula Marine Mammal Sanctuary (BPMMS), with a concentration of survey effort in and around Akaroa Harbour, allowing individuals to be identified and tracked over time. Gormley et al. (2012) published the results of demographic model fit to observations from 1986 to 2006. This found that the annual survival probability was likely to have increased after the establishment of the BPMMS, which was implemented in 1988 and extended to protect bays and harbours in 1989.

This re-analysis evaluated the robustness of their conclusions to alternative model structures and treatments of the mark-resighting data. The dataset used by Gormley et al. (2012) was not available to our assessment. However, a dataset was sourced from DuFresne (2004), that was derived from the same photographic catalogue, but for different time periods (1985 to 2002) and with more sightings in some years, allowing the model structure used by Gormley et al. (2012) to be replicated. We assessed the sensitivity of pre- and post-sanctuary survival estimates to: alternative parameterisations of the mark-recapture model; alternative temporal groupings of parameters; and to curtailing the time series of observations.

We found that the model structure used by Gormley et al. (2012) was preferable to other parameterisations, based on the leave-one-out information criterion (LOOIC). Post-sanctuary annual survival estimates were sensitive to:

- Model parameterisation, particularly the resighting probability component — with other parameterisations generally resulting in lower estimates for the post-sanctuary period; and
- The length of the time series used — with lower post-sanctuary survival estimates obtained when the final year of observations were excluded.

It is likely these patterns resulted from Markovian temporary emigration, i.e., the temporary disappearance of dolphins from the sightings record, which can be caused by changes in dolphin behaviour or of the spatio-temporal distribution of survey effort. The parameterisation of resighting probability used by Gormley et al. (2012) should, at least partially, have corrected for the resulting bias. Other options for more directly accounting for this bias are discussed.

In this analysis, contrary to the assessment by Gormley et al. (2012), post-sanctuary annual survival estimates were consistently lower than the pre-sanctuary period. This was caused by a combination of higher pre-sanctuary and lower post-sanctuary estimates relative to their assessment. This is likely a result of the inclusion of additional sightings in the period 1990–1992 that were excluded from the dataset used by Gormley et al. (2012). Reasons for this exclusion have not been clearly documented, and the consequences should be well-understood in a thorough assessment of the effectiveness of the BPMMS.

Spatial and temporal variation in survey effort will affect what can be reliably determined from the resulting data, and how parameter estimates should be interpreted. A greater level of scrutiny of the data, and the general design of field effort, e.g., to address the concentration of effort in and around Akaroa Harbour, should be undertaken if the results of the analyses are to be used by managers for policy setting. If the survival of Hector's dolphin within the BPMMS is of interest, then a study should be properly designed to ensure appropriate data are collected, in the appropriate manner. Consequently, if managers see potential value in such data, they should be prepared to financially support the programme in some manner.

We recommend that the outputs of the Gormley et al. (2012) assessment, and this re-analysis, should not be used to inform management decisions based on estimates of the effect of the BPMMS on survival rates of Hector's dolphins, without a better understanding of the effects of known changes in survey effort and refinements to the database through time — particularly on pre-sanctuary survival.

1. INTRODUCTION

1.1 Background

The Banks Peninsula Marine Mammal Sanctuary (BPMMS) was established in December 1988, specifically to protect resident Hector's dolphin (*Cephalorhynchus hectori*) from entanglement and associated mortality in commercial and recreational fishing gear. Dawson (1991) reported a minimum of 230 Hector's dolphin fatalities resulting from entanglement in commercial and recreational gillnets from 1984 to 1988, along the Canterbury coast of the South Island. This level of mortality is likely to have affected the survival rate of Hector's dolphins in places where the overlap between dolphins and fishing was high.

Since 1984/85 (hereafter referred to by end year, i.e., 1985), University of Otago researchers have developed a photographic catalogue of Hector's dolphin sightings made inside the BPMMS, with a concentration of survey effort in and around Akaroa Harbour, allowing individuals to be identified and tracked over time. This has previously been used by University of Otago researchers to assess temporal, spatial, and ontogenetic variability in annual survival probability (e.g., Cameron 1999, DuFresne 2004, Gormley 2009). The published assessment by Gormley et al. (2012) entitled "First evidence that marine protected areas can work for marine mammals" reported evidence for an increase in annual survival probability after the establishment of the BPMMS. This assessment has previously been used to inform managers about the historical effects of fishing on Hector's dolphins, and to justify the New Zealand Threat Classification status of the South Island sub-species (Baker et al. 2019).

1.2 Gormley assessment

Gormley et al. (2012) analysed the resighting data using a Cormack-Jolly-Seber (CJS) mark-recapture model, implemented in a Bayesian framework. Results were only presented for a single model, which assumed mean survival was different pre- and post-sanctuary, where the post-sanctuary period began with the 1989/90 field season. Annual variation about the mean survival was incorporated with a random effect. The probability of resighting an individual in year *t*, was modelled as a function of the number of times the individual was sighted in the previous year ($z_{i,t-1}$), to account for individual heterogeneity. The general form of the model was:

$$logit(p_{i,t}) = \alpha_t + \beta_t \left(\frac{z_{i,t-1} - 5}{10}\right)$$

which involves the estimation of two parameters for each year, α_t and β_t. Gormley et al. (2012) assumed the α and β parameters where random values from different normal distributions (i.e., random effects) rather than estimating the values independently of the other α or β parameters. They concluded from their model that there was a 90% probability that survival was higher in the post-sanctuary period. This was markedly different to the conclusion of Cameron et al. (1999), from a shorter time series, who found little evidence for a change, and that survival may actually have declined after the sanctuary was established.

1.3 Reanalysis

Given that only a single model was considered by Gormley et al. (2012), and no plots of model fits to observations were provided, it is difficult to ascertain how robust their conclusions are to alternative model structures, or treatments of the resighting data. The purpose of this reanalysis is to undertake such an assessment. Two lines of inquiry were conducted:

1. The first replicated the modelling approach of Gormley et al. (2012). This then allowed an analysis of the sensitivity of pre- and post-sanctuary annual survival estimates to assuming alternative model structures, focusing on:

- the effects of assuming random versus fixed effects, and
- the effects of making annual resighting probabilities contingent on the number of sightings in the previous year.

2. The second assessed the sensitivity of annual survival estimates to various groupings of model parameters, and the length of the time series used in the analysis.

This is followed by a discussion of the performance of different model structures, potential biases associated with certain structures, and approaches for accounting for any biases. We also discuss uncertainties and changes with respect to the provenance of mark-recapture observations through time, including decisions about what subsets of the data are included or excluded in various analyses, and the importance of considering these when using the outputs of BPMMS Hector's dolphin demographic models to inform management decisions.

2. METHODS

Hector's dolphin demographic assessment models were developed to explore the sensitivity of pre- and post-sanctuary annual survival estimates of the BPMMS population. Models were developed using JAGS (Just Another Gibbs Sampler) (Plummer 2012) and the SEABIRD demographic modelling software (Francis & Sagar 2012, Roberts et al. 2019) and were fitted to the photo-ID based mark recapture observations of Hector's dolphins from an ongoing survey of the Banks Peninsula population. These models were Bayesian to allow Markov chain Monte Carlo (MCMC) estimation of model parameters, though they specified uniform priors, such that the outputs were not constrained by prior assumptions of parameter distributions.

The mark-recapture dataset used by Gormley et al. (2012) was unavailable to evaluate the robustness of final inferences and the relative performance of different model parameterisations. However, the dataset used by DuFresne (2004) — an earlier extraction from the same photo identification catalogue — is publicly available as an appendix in his thesis, and this was used by this assessment.

2.1 Observations

Models were fitted to annual photo-ID based mark-recapture observations of Hector's dolphins collected from the BPMSS. The observations used by this assessment and associated field methods were previously reported by DuFresne (2004). The sample included all sightings made between Rakaia River and Sumner Head (i.e., the full extent of the BPMMS) and extending four nautical miles (7.5 km) offshore. Note that approximately two-thirds of survey effort in terms of survey days was concentrated within and around Akaroa Harbour (Bräger et al. 2002), such that the resultant model estimates will be most strongly influenced by the demographic rates of dolphins using Akaroa Harbour.

The boat-based field work producing these observations was predominantly conducted in Austral summers (predominantly November to March) from 1985 (the 1984/85 season) to 2002. Survey year is denoted in terms of the year of 1 January during the survey period (i.e., survey year 1994 refers to surveys conducted between November 1993 and March 1994). No surveys were undertaken in 1998 or 1999 due to commitments to abundance surveys undertaken in those years (Dawson et al. 2004). Individuals were classified as category I, II, or III based on the quality of the marks used to identify them, with category I individuals being most easily identified (see Slooten et al. 1992 for a description of these). Only resightings of category I and II individuals were reported by DuFresne (2004), which included 100 category I and 241 category II individuals. The assessment by DuFresne (2004) obtained very similar estimates of annual survival when fitting separately to the two categories. As such, no distinction was made between these in our assessment, nor was the information available for doing so.

A summary of the mark-recapture observations by year is given in Table 1. Models were fitted to binary presence/absence for each individual by year (e.g., see observations reproduced in Appendix G:), though some models also used sighting frequency in the previous year as a covariate of resighting probability, which was also reported by DuFresne (2004). Although the agreement between the datasets used by Gormley et al. (2012) and provided by DuFresne (2004) is very good in some years, in other years there is a substantially greater number of individuals recorded in the DuFresne dataset, particularly 1986, 1990–92, and 2001-02 (highlighted in Table 1). There was no survey effort in 1998 and 1999 and no individuals were sighted in these years.

Table 1: Number of sightings by year in the dataset used by this assessment (obtained from DuFresne 2004) compared with the assessment by Gormley et al. (2012; reproduced from their table 1). These are reported in terms of the number of individuals 'captured' for the first time each year (First), the number of captured individuals that had been captured in a previous year (Recap.), and the total number of unique individuals captured in each year (Total). Shading indicates years with a substantially greater number of individuals recorded in the DuFresne dataset.

	Available for this assessment			Used by Gormley et al. (2012)		
Year*	First	Recap.	Total	First	Recap.	Total
1985	9	0	9			
1986	72	5	77	62	0	62
1987	22	39	61	23	35	58
1988	29	58	87	34	51	85
1989	6	18	24	7	16	23
1990	7	16	23	4	5	9
1991	20	42	62	17	29	46
1992	26	46	72	14	28	42
1993	10	36	46	14	34	48
1994	7	39	46	9	39	48
1995	14	42	56	15	39	54
1996	8	25	33	8	25	33
1997	0	18	18	0	18	18
1998						
1999						
2000	32	8	40	30	6	36
2001	47	41	88	41	35	76
2002	32	64	96	34	50	84
2003				29	48	77
2004				24	48	72
2005				65	98	163
2006				32	92	124

*Year relates to summer field season, i.e. "1985" is the summer field season of 1984/85.

Because a different dataset was used by the assessment of Gormley et al. (2012) and this reanalysis, comparisons of annual survival estimates from the two assessments should be made with caution.

2.2 JAGS analyses

Cormack-Jolly-Seber model formulation

The CJS model was implemented in JAGS using a similar approach to Schofield et al. (2009) and Gormley et al. (2012). Namely, let $A_{i,t}$ indicate whether animal *i* was alive at period *t* (1 = alive, 0 = dead) and $X_{i,t}$ indicate whether animal *i* was sighted in period *t* (1 = sighted, 0 = not sighted). The $A_{i,t}$ and $X_{i,t}$ values are therefore Bernoulli random variables where:

$$A_{i,t+1} \sim Be(A_{i,t} S_t^{y_t})$$

and

$$X_{i,t} \sim Be(A_{i,t}p_{i,t})$$

with S_t being the probability of an animal surviving from period t to t + 1 (given it was alive in period t) and $p_{i,t}$ is the probability of resighting animal i in period t (given it was alive in period t). Note the multiplying S_t by $A_{i,t}$ ensures that an animal can only survive if it was alive in the previous period, and similarly multiplying $p_{i,t}$ by $A_{i,t}$ ensures that an animal can only be resighted in a period if it was alive in that period. Raising survival probabilities to the power of the number of years between periods (y_t) has the effect of annualising the estimated probabilities when there is an unequal number of years between survey periods.

Model parameterisations

Twelve models were fitted to the observations to evaluate the relative performance of different models. The 12 models were defined through a combination of three parameterisations of survival probabilities (Table 2) and four parameterisations of annual resighting probability (Table 3).

Table 2: Model identity, parameterisation, description, and parameter prior distributions used for survival component of model fit to Hector's dolphin data. $logis(a, b)$ denotes the logistic distribution with values between a and b, $\Gamma(a, b)$ denotes the gamma distribution with shape parameter a and scale parameter b, and $U(a, b)$ denotes the uniform distribution values between a and b.

Model ID	Parameterisation	Description	Prior Distributions
S1	$logit(S_t) = \mu_{Sj} + \epsilon_t$ • j = 1 for t = 1986 to 1989 • j = 2 for t =1990 to 2002 • $\epsilon_t \sim N(0, \sigma_S^2)$	• mean survival different pre- and post-establishment of the sanctuary • random effect for survey period	$\mu_{Sj} \sim logis(0,1)$ $\frac{1}{\sigma_S^2} \sim \Gamma(0.01,0.01)$
S2	$logit(S_t) = \mu_S + \epsilon_t$ • $\epsilon_t \sim N(0, \sigma_S^2)$	• constant mean survival • random effect for survey period	$\mu_S \sim logis(0,1)$ $\frac{1}{\sigma_S^2} \sim \Gamma(0.01,0.01)$
S3	S_t	• Fixed year-specific effect	$S_t \sim U(0,1)$

Survival model S1 assumes a different mean survival probability (on the logit scale) for the time periods 1986–1989 and 1990–2002, which is the same time structure used by Gormley et al. (2012) to represent pre- and post-sanctuary differences in survival. Annual variation about those means is assumed to be a random effect. Model S2 also assumes annual variation is a random effect, but with a constant mean for the whole period, whereas model S3 assumes annual variation in survival is a fixed effect. Note that in the modelling context, a 'fixed effect' refers to a factor whose associated parameters are estimated independently of each other, not that the parameters have been fixed to a particular value. In contrast, a 'random effect' assumes that the parameters associated with a factor are random values from a distribution. Because of the distributional assumption, estimates from a random effects model tend to be 'shrunk' closer to the mean value, where the degree of shrinkage depends on the sample size and distance from the mean (greater shrinkage for smaller sample sizes and more extreme values).

Table 3: Model identity, parameterisation, description, and parameter prior distributions used for resighting component of CJS model fit to Hector's dolphin data. $N(a,b)$ denotes the normal distribution with mean a and variance b, $U(a,b)$ denotes the uniform distribution values between a and b, and $Cat(a,b)$ denotes a categorical distribution where values and selected from a, with probability b.

Model ID	Parameterisation	Description	Prior Distributions
p1	$logit(p_{i,t}) = \alpha_t + \beta_t z^*_{i,t-1}$ • $\alpha_t \sim N(\mu_\alpha, \sigma^2_\alpha)$ • $\beta_t \sim N(\mu_\beta, \sigma^2_\beta)$ • $z^*_{i,t-1} = \frac{z_{i,t-1}-5}{10}$	• Resighting probability depends on number of sightings of the individual in previous period ($z_{i,t-1}$) • intercept and slope parameters are random effects for each survey period	$\mu_\alpha \sim N(0,1000)$ $\sigma_\alpha \sim U(0,100)$ $\mu_\beta \sim N(0,1000)$ $\sigma_\beta \sim U(0,100)$
p2	$logit(p_{i,t}) = \alpha_t + \beta_t z^*_{i,t-1}$ • $\beta_t \sim N(\mu_\beta, \sigma^2_\beta)$	• Resighting probability depends on number of sightings of the individual in previous period ($z_{i,t-1}$) • intercept parameter is fixed period-specific effect • slope parameters are random effects for each survey period	$\alpha_t \sim N(0,100)$ $\mu_\beta \sim N(0,1000)$ $\sigma_\beta \sim U(0,100)$
p3	$p_{i,t} \sim Cat(\boldsymbol{p}_t, \pi)$ $\boldsymbol{p}_t = [p_{1,t} \quad p_{2,t}]$ $p_{2,t} = p_{1,t} + \delta(1 - p_{1,t})$	• finite mixture, with mixing probability π • fixed year-specific base resighting probability ($p_{1,t}$) • constant proportional increase for second group (δ)	$p_{1,t} \sim U(0,1)$ $\delta \sim U(0,1)$ $\pi \sim U(0,1)$
p4	$p_{i,t} = p_t$	• Fixed year-specific effect	$p_t \sim U(0,1)$

Resighting models p1 and p2 depend on the number of times each individual was sighted in the previous year ($z_{i,t-1}$), which was standardised to improve convergence of model parameters (Gormley et al. 2012). These models allow for heterogeneous sighting probabilities (Fletcher 1994). Model p3 also allows for heterogenous sighting probabilities using a finite-mixture parameterisation (Pledger et al. 2003), whereas model p4 assumes equal sighting probabilities for all individuals within a year.

The combination of survival model S1 and resighting model p1 is the same parameterisation used by Gormley et al. (2012). Model fits using JAGS are denoted by the combination of model identifiers, e.g., model S1.p3.

Two additional models were fitted by the JAGS analysis that were also fit by the SEABIRD analysis. This was done to verify that analyses conducted using each software package were comparable, and to provide common references points between the analyses. Details on these models are given and are notated as models 1a and 2b (see Table 4).

Model comparison

Models were compared on the basis of the widely applicable information criterion (WAIC; Watanabe 2010) and leave-one-out information criterion (LOOIC) (Gelman et al. 2014), using the `loo R` package (Vehtari et al. 2019). The deviance information criterion (DIC) is automatically calculated when fitting models using the `jagsUI R` package (Kellner 2019), although it has been shown to be unreliable in some circumstances (Gelman et al. 2014), especially for mixture models or missing data problems (of which mark-recapture models can be considered a special case). Gelman et al. (2014) found that while WAIC and LOOIC are an improvement on DIC for model selection, they should be expected to give consistent results.

Evidence of poor model fit was assessed by comparing the observed and expected total number of individuals resighted in each year. Note that JAGS is a software package that is comparable to WinBUGS for analysing data in a Bayesian framework (as used by Gormley et al. 2012). All analyses were conducted within R using the `jagsUI` package to interface with JAGS.

MCMC runs

All JAGS-based analyses were conducted using three Markov chains of values, run for a total of 70 000 iterations, with the first 20 000 discarded as the burn-in period. Chains were not thinned. Chain convergence was assessed using Gelman's R-hat statistic.

2.3 SEABIRD analyses

Cormack-Jolly-Seber model formulation

CJS analyses of mark-recapture data can also be conducted using the SEABIRD demographic software, which can integrate information from mark-recapture, population size, and age distribution observations (e.g., Francis & Sagar 2012, Roberts et al. 2019). SEABIRD is written in C++ and gets the required information from input data files (see Appendix G:). Details of the likelihood calculations are given in Appendix B.

Model partition and parameterisation

The model partition was very simple with only two model classes: one for individuals marked within a year, and another for individuals resighted in subsequent years. This distinction was made to facilitate the processing of model fits using SEABIRD model outputs only. Because the SEABIRD models assigned the same survival probability to both classes, models would also have produced very similar, if not identical, parameter estimates if only one class was used instead.

Estimated model parameters were annual survival probability (*Surv*) and annual resighting probability (*Res*), and years or year blocks were estimated for each of these depending on the model run. All model parameters were specified as fixed effects. A summary of the different model runs using SEABIRD is given in Table 4. Uniform priors were assumed for all estimated model parameters.

Model comparison

For model pairs that used the same set of observations, model comparison was achieved using model Akaike information Criterion (AIC) (Akaike 1974). The aim was not to develop an optimal model for estimating annual survival. Instead, model comparison using AIC was used to assess the relative support for different model parameterisations.

MCMC runs

The MCMC was composed of a single chain of 2 000 000 iterations, with samples taken every 1000 iterations, giving a total of 2000 samples. The Metropolis-Hastings MCMC algorithm was used; this is relatively efficient in the absence of strongly correlated parameters. The assessment of MCMC mixing was based on the visual inspection of MCMC traces of estimated parameters.

Table 4: Summary of model runs. Maximum Posterior Density (MPD) runs were undertaken for all models and MCMC runs were undertaken for all except run 3c.

Model run ID	Model name	Basic description	Also run in JAGS
1a	Reference	Separate annual resighting probabilities for each year (1987 to 2012, though 1998–1999 fixed to zero); two survival years blocks for pre-sanctuary (1986–1989) and post-sanctuary (1990–2001). All model parameters are fixed effects. Model period from 1986 to 2002.	Yes
1b	Retrospective	Retrospective model runs using the 1a model parameterisation — final year of resightings iteratively removed from the model, giving 12 models in addition to 1a (which uses all years of resightings).	No
2a	Res_constant	As model 1a, except a single annual resighting probability applied to all years from 1987–2002.	No
2b	Res_block	As model 1a, except year – block used for annual resighting probability as follows: 1987–1988, 1989–1990, 1991–1995, 1996–1997, 1998–1999 (fixed to zero), 2000, 2001–2002.	Yes
3a	Surv_constant	As model 1a, except a single annual survival probability applied to all years from 1986–2001.	No
3b	Surv_annual	As model 1a, except a separate annual survival probability estimated for each year from 1986–2001 (with a year block of 1997–1999, because there was no resighting effort in 1998–1999).	Yes
3c	Surv_breakpoint	As model 1a, except moving the year breakpoint between two annual survival periods. A total of 12 model runs in addition to model run 1a (which uses 1986–1989 and 1990–2001, as per Gormley et al. 2012).	No
4	Start_1985	As model 1a, except model starts in 1985 and specifies a resighting probability for 1986. Slight change to observations also (see text above).	No

3. RESULTS

3.1 JAGS analyses

The traceplots of model parameters indicated that the MCMC chains achieved convergence (Appendix C), and R-hat statistics were all less than 1.1. The parameter traceplots do indicate some autocorrelation, although the large number of samples will mitigate any effects of this on estimates. Diagnostic plots suggest that the number of individuals resighted in each year is consistently underestimated by the p1 and p2 class of resighting models (see Appendix D), although not majorly so.

The posterior distributions for the parameters of the 1a and 2b models obtained using JAGS are essentially identical to those obtained using SEABIRD (Table E.1 and Table F.1). For example, the posterior mean and 95% credible interval (CI) from JAGS for the difference in survival from model 1a is –0.043 (–0.096, 0.011), and from SEABIRD –0.043 (–0.098, 0.011). This gives confidence that the mark-recapture models are being implemented consistently by the two software packages, and results are directly comparable.

DIC appears to be an unreliable metric for comparing the model fit in JAGS, given the fundamental differences in the various model structures (i.e., random vs. fixed effects, finite mixture model, etc.).

The large ΔDIC values between some models (Table 5) indicate large differences in the performance of the model, but that does not appear to be substantiated upon inspection of the estimated posterior distributions for the model parameters (posterior distributions were similar in some instances from models with large ΔDIC values). Similarly, WAIC would indicate that models with the p3 resighting probability structure (i.e., finite mixture to account for heterogeneity) are preferred. However, the estimates from these models are almost indistinguishable to those from the p4 family of models (no heterogeneity). In addition, warning messages given (by the R package) during the calculation of the WAIC values that suggested LOOIC should be considered. The ranking of the models on the basis of LOOIC was consistent with the estimated parameter posterior distribution from the individual models. Hence LOOIC was the main diagnostic used for model comparison.

Based on LOOIC, the p1 and p2 class of resighting models (using the number of sightings of an individual in a previous year as a covariate for resighting probability) were better than the p3 and p4 family of models (resighting probability not contingent on the previous year's sightings), for all three different structures for survival probabilities. The S2 models, which assume a constant mean for the whole period with random year-specific effects, are slightly preferred over the S1 models (where mean survival differed pre- and post-sanctuary establishment) that are, in turn, slightly preferred over the S3 class of models (i.e., survival models with fixed year-specific effects). This result is supported by the difference in mean survival for the pre- and post-sanctuary periods from model S1.p1 being small with a relatively wide credible interval ($\Delta S = -0.017$; 95% CI = –0.093, 0.081). Note that the p1 and p2 classes of models are also ranked much higher than the models 1a and 2b (using LOOIC), and model 2b was the highest-ranked model considered in the SEABIRD analysis. Figure 1 compares the posterior distribution for the survival probabilities from models 1a and 2b, along with the posterior distribution of mean survival from model S1.p1. The difference in pre- and post-sanctuary establishment is much smaller under model S1.p1.

Table 5: Summary of the model comparison procedure. Presented is the relative difference in DIC, WAIC, and LOOIC values (relative to the model with the smallest value of that metric).

Model ID	ΔDIC	ΔWAIC	ΔLOOIC
1a	14.52	118.93	83.49
2b	0.00	115.21	77.97
S1.p1	286.10	74.84	1.61
S1.p2	396.47	78.50	3.24
S1.p3	11453.81	25.83	37.26
S1.p4	122.22	119.12	86.01
S2.p1	280.55	72.11	0.00
S2.p2	364.21	75.40	0.00
S2.p3	11752.34	22.03	34.43
S2.p4	100.65	114.92	84.80
S3.p1	128.41	39.93	4.30
S3.p2	267.64	46.55	5.36
S3.p3	11866.65	0.00	37.02
S3.p4	922.50	96.37	87.68

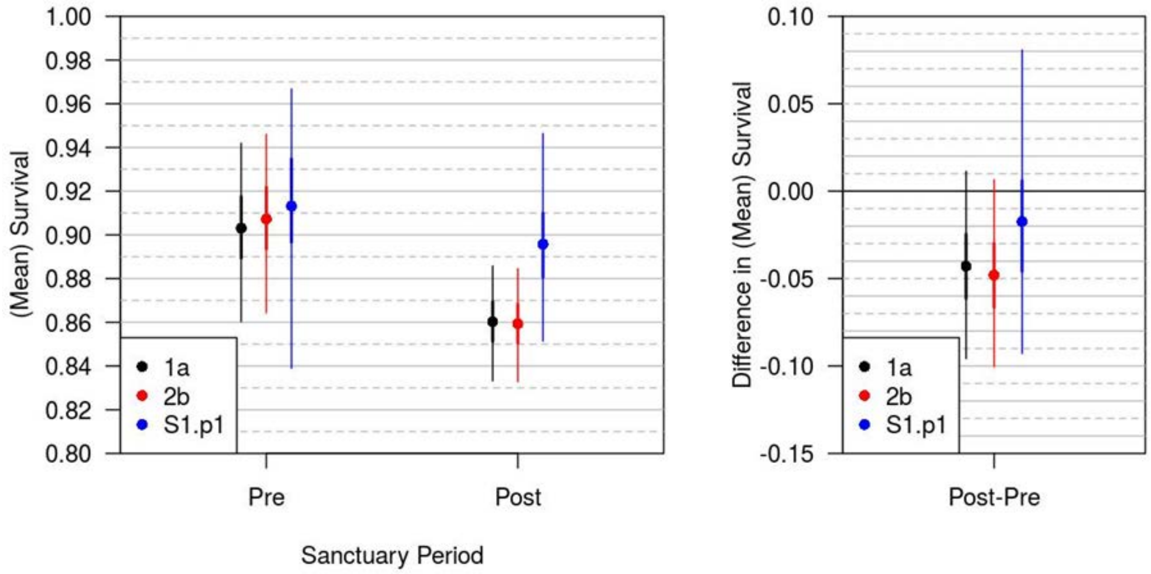


Figure 1: Posterior distributions for the survival probabilities from models 1a and 2b (see Table 4), and posterior distribution of mean survival from model S1.p1 (i.e., reproducing the structure and parameterisation of Gormley et al. 2012), for pre- and post-sanctuary establishment. All results are from the JAGS analyses. The posterior means, central 50% credible interval, and central 95% credible interval are presented.

For all S1 models (two survival periods with random year-specific effect), mean survival was estimated to be greater for the pre-sanctuary period, although the difference was much less when the number of sightings in the previous year was used as a covariate for the resighting probabilities (i.e., models p1 and p2; Figure 2, Table E.2). Estimated survival probabilities were consistently higher using the p1 and p2 models, whereas the survival estimates from the p3 and p4 models were similar.

Comparable results were obtained from the S2 model (single period with random year-specific effect), with estimates from the p1 and p2 being similar, as were the estimates from the p3 and p4 models. The estimates from the former models were higher than those from the latter models (Figure 3, Table E.3)

Survival estimates from the S3 models (fixed year-specific effects) were more variable (Figure 4, Table E.4) and with greater uncertainty, than those from the random effect models (S1 and S2). Generally, the estimates from the p1 and p2 models were greater than those from the p3 and p4 models, although in some years the estimates were very similar. Note that, when there is a fixed year-specific effect on both survival and resighting probabilities (i.e., models S3.p3 and S3.p4), the final survival and resighting probabilities were confounded and the resulting estimates should be ignored.

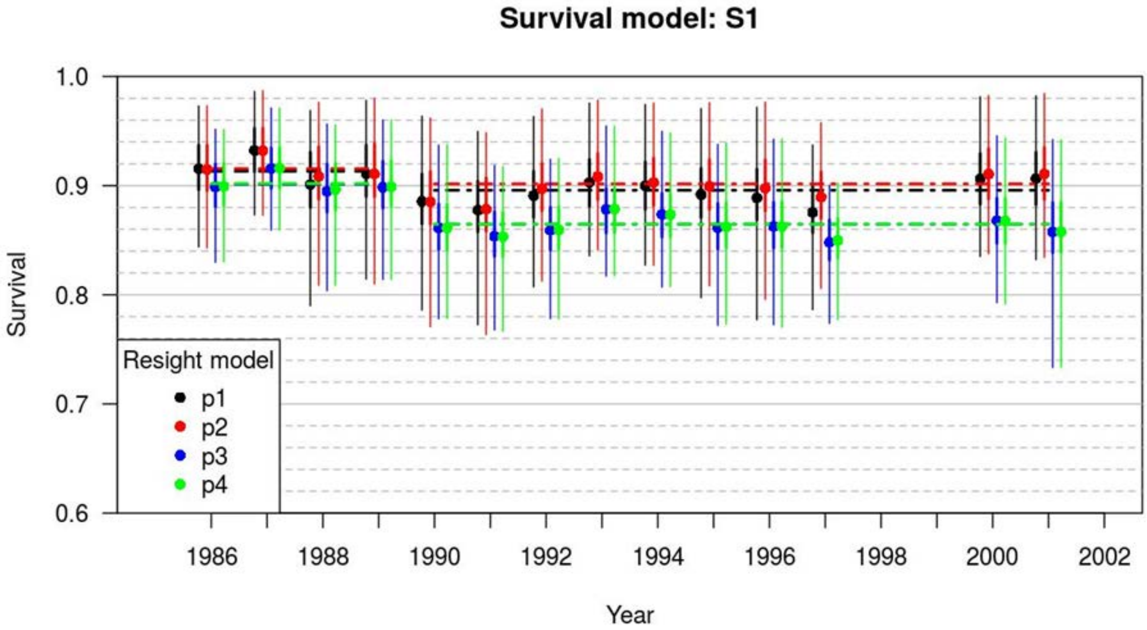


Figure 2: Estimated posterior distributions for annual survival from model S1 (two survival periods, random year-specific effect), for each resighting model, using JAGS-based analysis. The posterior mean, central 50% credible interval, and central 95% credible are indicated for each year. The posterior mean of mean survival in each period is also indicated for each model.

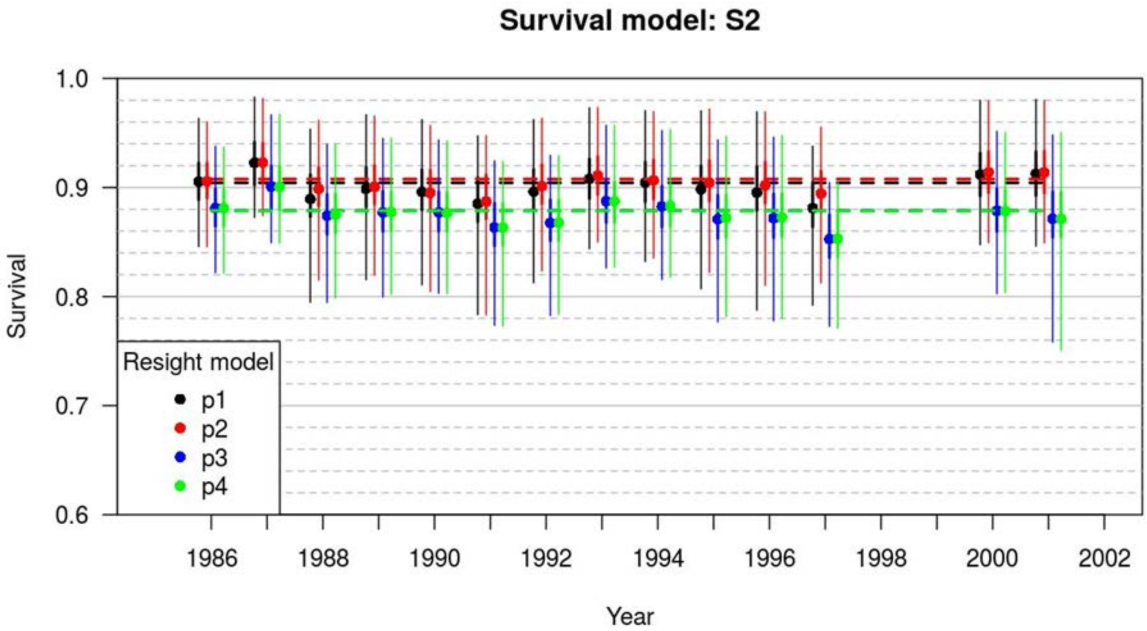


Figure 3: Estimated posterior distributions for annual survival from model S2 (single survival period, random year-specific effect), for each resighting model, using JAGS-based analysis. The posterior mean, central 50% credible interval, and central 95% credible are indicated for each year. The posterior mean of mean survival in each period is also indicated for each model.

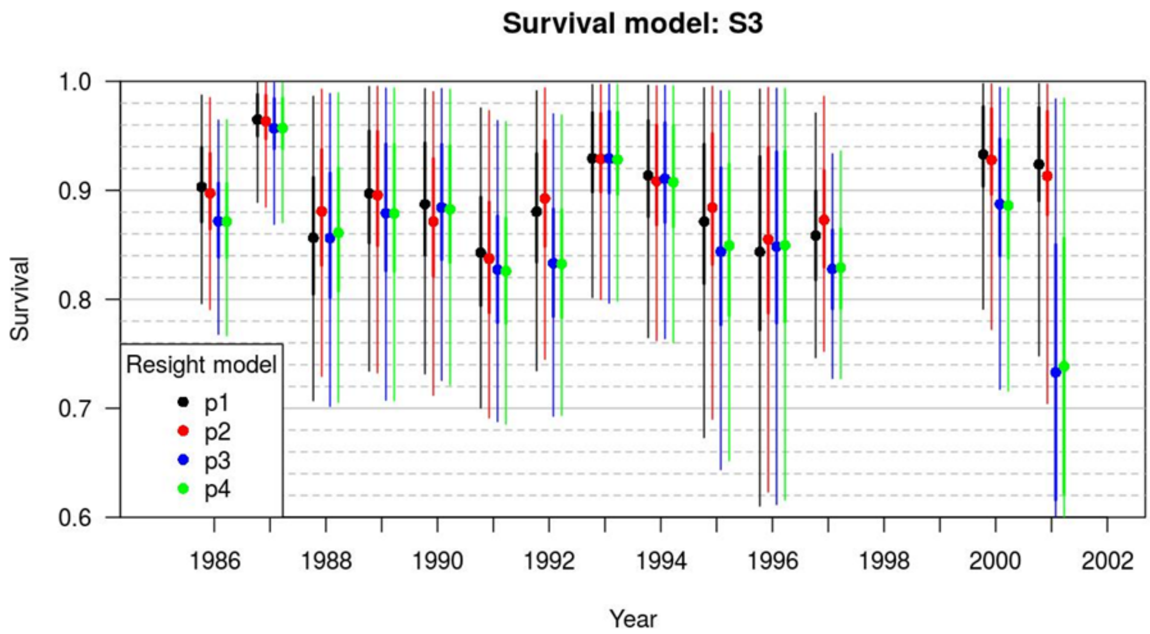


Figure 4: Estimated posterior distributions for annual survival from model S3 (fixed year-specific effect), for each resighting model, using JAGS-based analysis. The posterior mean, central 50% credible interval, and central 95% credible are indicated for each year. Survival in 2001 is confounded with other parameters when using resighting models p3 and p4, so should be ignored.

3.2 SEABIRD analyses

Maximum Posterior Density (MPD) model runs

MCMC estimates are likely to be more robust than those from MPD runs and were undertaken for all model structures runs for which survival was estimated. As such, MPD outputs are displayed for assessment model fits and for model comparison only, and parameter estimates are shown for MCMC runs only and discussed in the next section.

Model fits to mark-recapture observations are shown for the reference model run (run 1a) (Figure 5). Model fits were very good, as would be expected for a model with separate annual resighting probabilities for each year (Figure 5, left). The predicted number of resightings was within two individuals of the observed values for any year (Figure 5, right).

The reference model (run 1a), which specified two annual survival year blocks ($Surv_{pre}$ and $Surv_{post}$), was found to be marginally better in terms of model AIC, compared with the model that had a single survival year block (by only 0.46 AIC units). The best model in terms of AIC (run 2b) assumed six annual resighting probability year blocks (instead of annual values), representing shifts in annual resighting probability through time (Table 6).

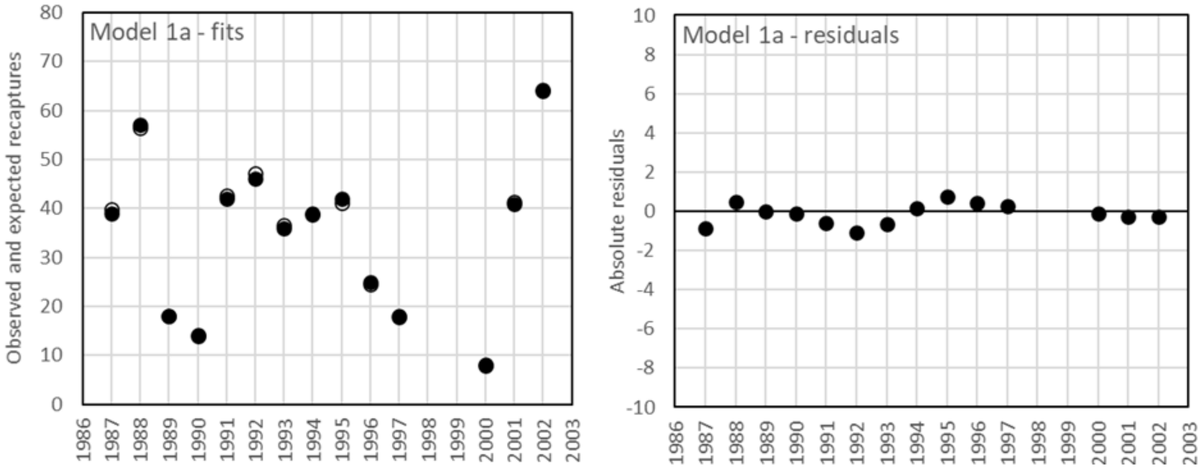


Figure 5: Fits to mark recapture (left) and associated residuals (right) for model run 1a (the reference model).

Table 6: Comparison of models fitted to the same set of observations, with respect to log-likelihood of the observations, the total number of estimated parameters, and model AIC. See Table 4 for a description of each model.

Model ID	Model name	Log-likelihood	Estimated parameters	AIC	ΔAIC
1a	Reference	1004.19	16	2040.38	7.32
2a	Res_constant	1077.19	3	2160.38	127.32
2b	Res_block	1008.53	8	2033.06	0.00
3a	Surv_constant	1005.42	15	2040.84	7.78
3b	Surv_annual	999.576	28	2055.15	22.09

MCMC model runs

The MCMC traces indicate that good mixing was achieved for all estimated model parameters in model 1a (Figure F.1), and that the chain length was sufficient for obtaining stable estimates.

The resighting probability estimates for the reference model run (1a) (Table F.1) are consistent with those of previous demographic models fitted to the same observations (see table 3.8 of DuFresne 2004; note that the corresponding run assumed a multi-area model structure). The estimated resighting probability was initially between 0.40–0.80, before dropping to 0.05–0.30 in 1989 and 1990, i.e., in the two years prior to the implementation of the BPMMS, as assumed by Gormley et al. (2012). Estimated resighting probability then increased again to 0.25–0.60 from 1990 to 1995, before decreasing again, and then increasing at the end of the model time period (0.40–0.75 in 2001 and 2002). For the period up to 1993, the temporal pattern in resighting probability agreed well with the annual number of days' effort reported in Table 1 of Cameron et al. (1999). This pattern was primarily driven by changes in the spatial distribution and intensity of resight effort through time, rather than the changes in survey methods or the behaviour of the dolphins.

All models that had the second survival year block ($Surv_{\text{post}}$) starting in 1990 (consistent with Gormley et al. 2012) (all except model runs 3a, 3b, and 3c) obtained a reduction in survival in the second survival period. For example, the reference model (1a), which was most like the Gormley et al. (2012) model structure, produced annual survival estimates of 0.903 (95% credible interval (CI) = 0.859 – 0.941) for 1986–1989 and 0.860 (95% CI = 0.832 – 0.885) for 1990–2001 (Table F.1). The corresponding change in survival between periods was estimated to be -0.043 (95% CI = -0.098 – 0.011), and approximately

95% of the posterior estimated a decrease survival (note that a large proportion will have been close to no change). The survival parameters were relatively insensitive to the parameterisation of resighting probability, although the drop in survival between periods was reduced when assuming a constant resighting probability -0.012 (95% CI = -0.060 – 0.038) (run 2a). The model parameters were essentially unchanged when the model was started in 1985 instead of 1986 (run 4 compared with run 1a) (Table F.1).

A retrospective set of model runs was undertaken (run 1b), where model parameters were estimated after iteratively removing the final year of resightings. The model tended to produce lower annual survival estimates for year blocks that were associated with few years of resighting effort. Survival estimates stabilised once there was around six years of resighting effort associated with it, i.e., in 1992 for $Surv_{\mathrm{pre}}$ (1986–1989), and in 1996 for $Surv_{\mathrm{post}}$ (1990–2001) (Table F.2). Thus, when using the full time series of observations, the model period should be sufficient to prevent terminal bias in estimates for the final survival year block (e.g., Langtimm 2009, Langtimm et al. 2004), given the level of resighting effort. However, $Surv_{\mathrm{post}}$ increased abruptly with the addition of the final year of resightings in 2002, from 0.824 (0.790–0.857) omitting this year, up to 0.860 (0.833–0.888) when it was included. This would be consistent with a number of dolphins being seen in 1992 that were not seen for a number of years previously, i.e., temporary emigration or restriction in survey area could negatively bias the $Surv_{\mathrm{post}}$ estimate without this final year of resightings (Peñaloza et al. 2014).

Note that the estimates of the retrospective model run from 1986 to 1993 were consistent with a multi-area assessment by Cameron et al. (1999) [this assessment — $Surv_{\mathrm{pre}}$ = 0.890 (0.836–0.941), $Surv_{\mathrm{post}}$ = 0.798 (0.689–0.921); Cameron assessment — $Surv_{\mathrm{pre}}$ = 0.93 (standard error (SE) = 0.04), $Surv_{\mathrm{post}}$ = 0.79 (SE = 0.06)].

Another set of model runs was undertaken to explore the effects of selecting alternative breakpoints between the two survival year blocks (run 3c). Regardless of which year the breakpoint was set to, the estimate of $Surv_{\mathrm{post}}$ was lower than $Surv_{\mathrm{pre}}$, consistent with a decline in survival (Table F.3). Note that, based on the retrospective analysis (run 1b) (see above), $Surv_{\mathrm{post}}$ is likely to have been biased low for all models with a breakpoint set at 1995 or later, due to terminal bias (i.e., fewer than 6 subsequent years of resighting effort). Based on the likelihood distributions of the retrospective models, there is extremely limited support for selecting any year breakpoint over another, including the 1990 model run, which corresponds with the start of the BPMMS, as assumed by Gormley et al. (2012) (Figure 6).

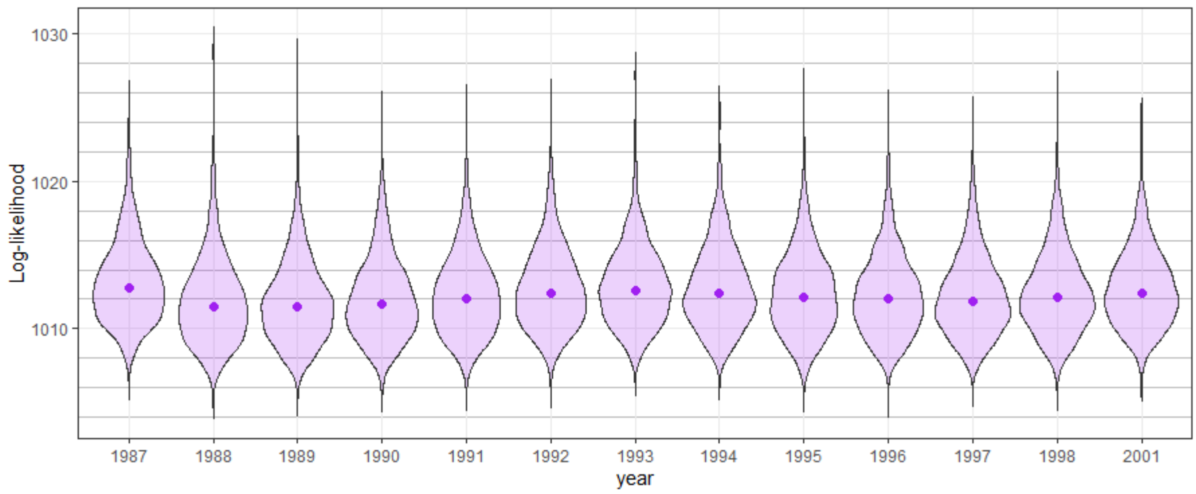


Figure 6: Violin plots of log-likelihood of observations from MCMC runs of models using alternative breakpoints between survival year blocks (run 3c). The year shown here is the first year of the second survival year block, e.g., the “1990” model specified annual survival years blocks from 1986–1989 and 1990–2001. Points represent medians.

4. DISCUSSION

4.1 Overall results

The results of the analyses conducted in JAGS suggest that the structure used by Gormley et al. (2012) for modelling resighting probabilities is preferable to using a finite-mixture model structure or a structure that assumes no heterogeneity. Gormley et al. (2012) presented their resighting model as a method to account for heterogeneity, which could be due to the behaviour of individual dolphins (e.g., some may be more attracted to boats), but heterogeneity can also be induced by temporary emigration or spatially variable patterns of resight effort between years (i.e., individuals are not always available to be resighted in every year).

Estimates of survival using the CJS model are robust to the effects of random temporary emigration (where the probability of an individual being available for detection does not depend on whether they were available in the previous survey), because the availability probability becomes a component of the resighting probability in each year. However, Markovian temporary emigration is more problematic and can bias estimates of survival (Schaub et al. 2004), and particularly result in terminal bias (bias at the end of the time series; Langtimm et al. 2004), which was demonstrated in the SEABIRD analyses. With Markovian temporary emigration, the probability of an individual being available in each survey period depends on whether it was available in the previous period. It can be the result of animal movement patterns, spatial variation in survey effort, or a combination of both, as we believe to be the case here.

Cameron et al. (1999) and DuFresne (2004) used multi-state mark-recapture models to analyse photographic captures of this Hector's dolphin population, where 'states' were defined as geographic regions around the BPMMS. The multi-state model assumes that changes in states follows a Markovian process, although if the probability of being in state i at time t+1 was similar for all states at time t, that would suggest the movement between states is a random process. The results of Cameron et al. (1999) and DuFresne (2004) strongly indicate movement by Hector's dolphin between geographic areas of the BPMMS is Markovian, with animals tending to remain in the same, or a neighbouring area, between years. However, importantly, their results also indicate there is a non-negligible probability of animals moving to other areas between years.

It is known that the spatial distribution of survey effort within the BPMMS has changed though time (Cameron et al. 1999, Bräger et al. 2002). Although Akaroa Harbour has been a core monitoring area, more exposed (and therefore difficult to survey) areas of the BPMMS have generally been surveyed with less effort, but with greater effort in some areas in some years. This spatially sporadic survey effort changes the composition of animals that are available to be seen in any given year. Individuals that tend to remain in areas that are consistently surveyed are more likely to be available in consecutive years, whereas individuals in areas that are sporadically surveyed are less likely to be available in consecutive years.

Akaroa Harbour is narrow enough to be fully sampled every year, but outside Akaroa Harbour survey effort was limited to within 4 nm of shore; however, in most locations the spatial distribution of the dolphins extends further offshore (especially in Pegasus Bay, north of Banks Peninsula). Thus for survey strata on the open coast, inshore-offshore movements of individual dolphins (not just lateral movements) will affect their availability to be resighted by the survey.

Using the number of sightings of an individual in the previous year may act as a proxy to account for the effects of Markovian temporary emigration to some extent, although there are more mechanistic modelling approaches available. In particular, the general manner in which the data have been collected is potentially compatible with Pollock's robust design which can be used to account for Markovian temporary emigration (e.g., Kendall et al. 1997, Peñaloza et al. 2014).

Given known spatial variability in survey effort, with much greater sampling in Akaroa Harbour, we strongly suggest that any estimates of survival derived from this photographic catalogue should not be considered representative of the entire BPMMS or the larger subpopulation, which extends beyond the boundaries of the BPMMS. Furthermore, we note that permanent emigration of dolphins from the surveyed areas induces a negative bias in survival (DuFresne 2004), and that even relatively small biases may have severe consequences on our understanding of the dynamics for this population, with respect to population growth rate.

4.2 Comparison with previous assessments

The assessment by Gormley et al. (2012) obtained an approximate 5% increase in the annual survival of Banks Peninsula Hector's dolphins following the implementation of the BPMSS, although with a low degree of precision. Our re-analysis obtained a decline in annual survival probability post-implementation of the BPMSS, regardless of the model structure used, and even when the model structure of Gormley et al. (2012) was replicated in JAGS (model S1.p1; Figure 7). Conversely, our parameter estimates were consistent with the outputs of Cameron (1999) and DuFresne (2004), from which the mark-recapture observations we used were obtained.

When replicating the model structure used by Gormley et al. (2012), survival was estimated to be higher in the pre-sanctuary period using the current data relative to the estimate obtained by Gormley et al. (2012). Post-sanctuary survival is estimated to be slightly lower using the current dataset, whereas temporal variations appear similar in both.

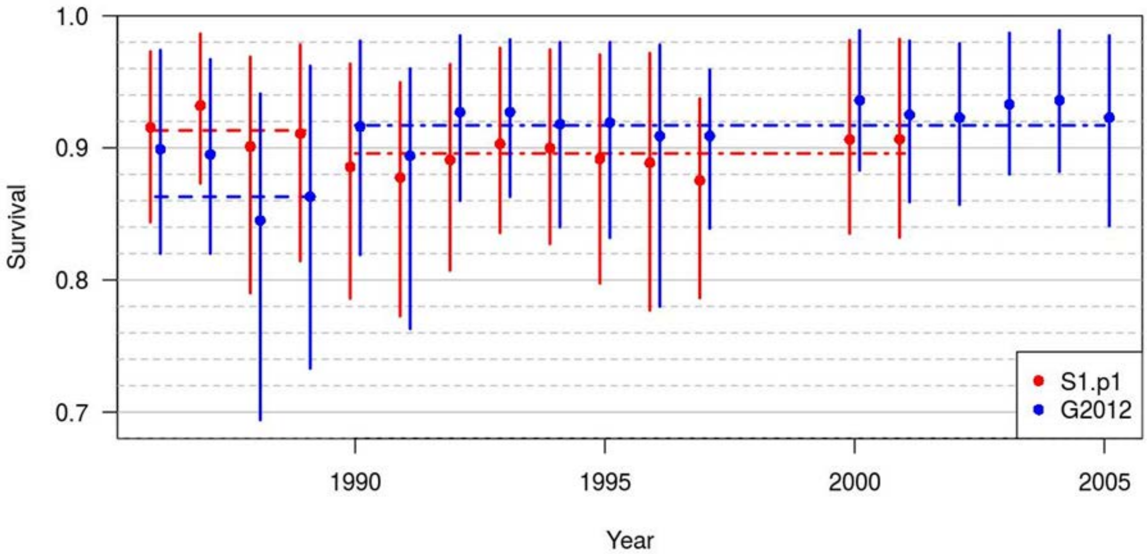


Figure 7: Comparison of estimated survival probabilities obtained from the data used in this assessment (S1.p1) to those reported by Gormley et al. (2012; G2012). Presented is the posterior mean and central 95% credible interval. Horizontal lines indicate the posterior mean of the mean survival probability from each assessment for the defined pre- and post-sanctuary periods.

Therefore, we conclude that the reversal in the change in annual survival relative to the assessment by Gormley et al. (2012) must have been driven by our reanalysis being fitted to a different data subset. An explanation that is consistent with the lower pre-sanctuary survival obtained by Gormley et al. (2012) is that there are dolphins which were recorded as sighted in both datasets pre-sanctuary, which are recorded as sighted post-sanctuary in the current dataset, but are not present in the dataset used by Gormley et al. (2012). Notably, the assessment by Gormley et al. (2012) reported 5, 29, and 28 recaptures in 1990, 1991, and 1992 respectively, compared with 16, 42, and 46 recaptures respectively in the DuFresne (2004) dataset, whereas the number of recaptures was much closer in subsequent years (except 2002; see Table 1). The non-inclusion of these recapture sighting records following the establishment of the sanctuary is likely to depress estimates of pre-sanctuary survival. Simultaneously, the non-inclusion of sighting records from the early 1990s could increase estimated survival post implementation of the BPMMS if the excluded records are of individuals that were sighted in the early 1990s, but not resighted after 1992. Higher post-sanctuary survival obtained by Gormley et al. (2012) could also be the result of the additional years of data utilised, which would further reduce the effects of terminal bias caused by Markovian temporal emigration, particularly given no photographic surveys were conducted in 1998 and 1999.

An alternative cause of Gormley et al. (2012) obtaining a lower pre-sanctuary survival estimate would be if the earlier resighting record was not included in their dataset, but the post-sanctuary sighting was included, which then becomes the first recorded sighting of that individual in the dataset for analysis. Knowledge that the individual was known to be alive previously would, thus, be lost from the analysis.

A review of published sources (i.e., Bräger et al. 2002, DuFresne 2004, Gormley et al. 2005, Gormley 2009, Gormley et al. 2012) found only one stated possible difference between the two datasets: that the assessment by Gormley et al. (2012) excluded sightings obtained inside the BPMSS between Birdlings Flat and Rakaia River, which were retained in the DuFresne (2004) dataset that was used by this assessment. However, sighting effort in the region excluded by Gormley et al. (2012) was historically very low (see figures 5.2 and 5.3 of Rayment 2008), and this does not appear to be sufficient explanation for the large differences in individuals resighted in some years, i.e., in 1990 to 1992 (see Table 1). A comparison of table 2 of Bräger et al. (2002) and table 1 of Cameron et al. (1999) indicates there may have been substantial effort between Birdlings Flat and Rakaia River in 1986 and 1987 (Table 7). However, there are also other discrepancies in the reported effort; Cameron et al. (1999) recorded more effort north of Akaroa Harbour in 1986–1988. We note that the 1989–1997 portion of the DuFresne dataset appears to be nearly identical to that used by Gormley et al. (2005) to estimate Hector's dolphin abundance at Banks Peninsula (Appendix A). This suggests an unreported change in the data between the assessments by Gormley et al. (2005) and by Gormley (2009) or Gormley et al. (2012).

Table 7: Number of days of survey effort around Banks Peninsula from table 2 of Bräger et al. (2002) and table 1 of Cameron et al. (1999). Effort identified by regions: NW = Godley Head – Wakaroa Point, NE = Wakaroa Point – Steep Head , SE = Steep Head – Te Ruahine Point, AH = Akaroa Habour, SW = Timutimu Head – Birdlings Flat, N = Godley Head –Te Ruahine Point, S = Timutimu Head to Rakaia River. The inferred minimum days of survey effort between Birdlings Flat (BF) and Rakaia River (RR) is indicated.

Field	Bräger et al. (2002)					Cameron et al. (1999)			Inferred
Year	NW	NE	SE	AH	SW	N	AH	S	BF to RR
1985	1	1	1	2	1	1	2	1	0
1986	1	1	2	92	3	11	92	30	27
1987	0	1	5	79	6	25	79	27	21
1988	1	1	3	68	2	11	68	6	4
1989	0	0	0	19	0	1	19	0	0
1990	1	0	1	24	1	5	24	3	2
1991	22	20	4	23	9	30	23	11	2
1992	28	22	9	44	15	48	44	16	1
1993	2	2	4	19	14	9	19	16	2
1994	2	2	7	80	21				
1995	3	1	6	62	16				
1996	5	4	5	52	12				
1997	4	3	3	29	6				

A spatial and temporal breakdown of survey effort is not provided by Gormley (2009) or Gormley et al. (2012). Presuming that the effort reported by Bräger et al. (2002) is reflective of the data used by Gormley (given the comparable timeframe), then survey effort was primarily limited to Akaroa Harbour pre-1991, with an increase in effort in other areas from 1991 onwards. There were two years of higher effort between Godley Head and Steep Head in 1991 and 1992 (Smith 1992), and consistently higher effort between Timutimu Head and Birdlings Flat from 1991–1997. Rayment (2008) provides graphical summaries of survey effort around Banks Peninsula (excluding effort of Smith 1992) that is approximated in Figure 8, which also clearly indicate there have been spatial changes in the survey effort over time, with greater effort outside Akaroa Harbour. Changes in the spatial extent of the survey effort affects the effective study area being surveyed.

Survival estimates from the CJS mark-recapture model are the combination of true survival probability and the probability of remaining in the study area. When the effective study area changes over time (as it clearly has here), then the probability of a dolphin being available to be sighted within the varying study area will also change over time. DuFresne (2004) showed this to be untrue, finding notable levels of movement between areas in successive years. For example, the probability of individuals remaining in Akaroa Harbour in successive years was estimated to be 0.68 (table 4.7 of DuFresne 2004). Therefore, the probability of dolphins remaining in the effective study area was likely to be lower pre-1991, hence CJS survival estimates should also be expected to be lower pre-1991. This period of more limited survey effort largely coincides with the pre-sanctuary period defined by Gormley et al. (2012).

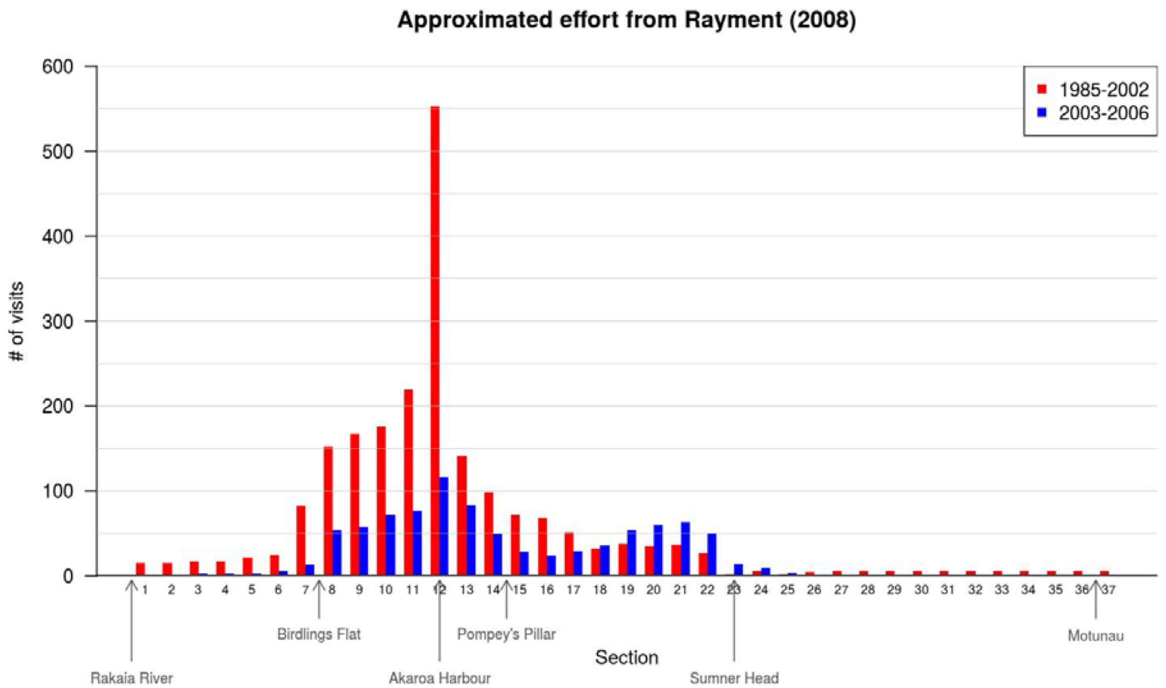


Figure 8: Number of visits to sections of the coast around Banks Peninsula in two time periods from Rakaia River (section 1) to north of Motunau (section 37). Approximated from figures 4.11 and 5.3 of Rayment (2008). Excludes survey effort of Smith (1992).

4.3 Evidence for changing survival from this assessment

Previous assessments using the Banks Peninsula Hector's dolphin mark-recapture dataset have explored models using constant survival across the model period, or two survival year-blocks consistent with periods before or since the introduction of the BPMMS (Cameron et al. 1999, DuFresne 2004, Gormley et al. 2012). We found that the two-survival year block parameterisation was almost indistinguishable from the model assuming constant survival, based on LOOIC for the JAGS analysis (Table 5) and based on AIC for the SEABIRD analysis (Table 6). Furthermore, the medians of the likelihood distributions from models using alternative breakpoints between survival year blocks spanned less than two units of log-likelihood across all model runs. This indicates that the mark-recapture observations used in this assessment were almost equally supportive of any placement of the breakpoint between survival year blocks (Figure 6).

4.4 Start of effective protection

The BPMMS was established in December 1988, i.e., near the beginning of the 1988/89 field season, which has been referred to as the 1989 survey year. Gormley et al. (2012) defined the final survival probability in the pre-sanctuary period to be 1989, which is the probability of survival between 1989 and 1990, and the first post-sanctuary survival to be 1990. Cameron et al. (1999) do not explicitly state which survival probabilities were assigned to the pre- and post-sanctuary establishment periods, though, conversely, gave the year of establishment as 1988. An unstated assumption was made by Gormley et al. (2012) that the BPMMS provided no beneficial effect to Hector’s dolphin survival in its first year of operation. This decision could be justified on the basis that a large proportion of the photo-ID survey effort was in Akaroa Harbour, which was not fully protected in the first year of the BPMMS.

There was a considerable reduction in reported commercial setnet effort off the east coast of the South Island after 1985/86 with the introduction of the Quota Management System (QMS). For example, an 83% reduction in commercial setnet effort was calculated for fisheries General Statistical Area 022, which includes the Canterbury Bight and southern half of Banks Peninsula (Davies et al. 2008). This is consistent with the reduction in reported landings of rig (*Mustelus lenticulatus*) after 1985/86, which was historically the largest commercial setnet fishery off the east coast of the South Island (ECSI). Rig landings in fishery area SPO 3 (which includes ECSI, Southland, and Fiordland) decreased from 921 tonnes in 1985/86 (and consistently more than 1000 tonnes each year in the late-1970s and early-1980s) to 312 tonnes in 1986/87 and did not exceed 500 tonnes in all subsequent years of the Gormley et al. (2012) assessment (Fisheries New Zealand 2018).

The major reduction in commercial setnet effort after 1985/86 is a strong candidate for the cause of the reduction in the annual incidental mortalities of Akaroa Harbour Hector’s dolphins in commercial setnets estimated by Dawson (1991), from a minimum of 58 and 92 individuals in 1984/85 and 1985/86, respectively, down to 32 and 18 individuals in the next two years. The introduction of the QMS preceded the first implementation of the BPMMS by two years and, on the basis of the major reduction in fishing effort, may have had a greater effect on Hector’s dolphins around Banks Peninsula than the implementation of the BPMMS, two years later. However, the mark-recapture survey only has one year of resighting effort prior to the introduction of the QMS and cannot be used to assess the demographic consequences of this earlier change in the setnet fishery.

4.5 Conclusions

Our assessment concludes that the general model structure used by Gormley et al. (2012) is preferable in comparison to other parameterisations that could have been considered for the CJS model, particularly with respect to the structure used for resighting probabilities (using number of sightings in previous year as a covariate for the probability of resighting).

However, our results indicate that survival estimates can be sensitive to the choice of model structure for the resighting probability, and to the length of the time series used for the analysis. This is most likely due to the effects of Markovian temporary emigration, which can bias survival estimates, that has arisen through a combination of Hector’s dolphin biology and the spatio-temporal distribution of survey effort. The structure of the resighting model used by Gormley et al. (2012) is a proxy for a more mechanistic explanation of the temporary emigration process. A better approach would be use multi-state mark-recapture models (e.g., Cameron et al. 1999, DuFresne 2004), possibly in combination with Pollock’s robust design to better utilise the within-season resightings of individuals. We note that Markovian temporary emigration can be a cause of heterogeneous resighting probabilities, although there may also be other sources that may need to be accounted for in an analysis.

The survival estimates obtained during our assessments were consistently very different to those obtained by Gormley et al. (2012). In particular, we estimated pre-sanctuary survival to be much higher and found a low probability (i.e., approximately 30%) that mean survival may have increased post-sanctuary. This is undoubtedly due to the different datasets used in the two assessments. Some resighting data that are available within the Hector’s dolphin photographic catalogue held by University of Otago researchers, and have been used by other researchers, were not included in the analysis of Gormley et al. (2012) and the reasons for the exclusion were not clearly documented. The consequences of excluding any data collected within the BPMMS should be well understood in a proper assessment of the effectiveness of the sanctuary on Hector’s dolphin survival.

Survey effort within the BPMMS has been spatially and temporally sporadic, which is understandable given the lack of long-term funding for fieldwork. However, this variation in field effort has consequences for what can be reliably determined from the resulting data, and how parameter estimates should be interpreted. For example, pre-1991, very little survey effort was conducted outside Akaroa Harbour; hence the survival estimates for that period may relate to the probability of dolphins surviving, and also staying in Akaroa Harbour, rather the survival in the BPMMS in general. With greater effort outside Akaroa Harbour from 1991 onwards, survival estimates may be more reflective of survival in the BPMMS. A greater level of scrutiny of the data, and the general design of field effort (e.g., along-shore surveys), should be undertaken if the results of the analyses are to be used by managers to understand the likely effects of fishing on Hector’s dolphins, to inform policy setting. Consequently, if managers see potential value in such data, they should be prepared to financially support the programme in some manner.

It is not uncommon for mark-recapture studies to evolve over time, rather than being properly designed for a single consistent purpose from the outset. The importance of appropriate spatial coverage for the population of interest is often underappreciated by practitioners who may be focused on capturing, and recapturing, individuals. Inappropriate study design may lead to biased estimates of demographic parameters, or estimates may not truly relate to the stated population of interest. If the survival of Hector’s dolphin around the BPMMS is of interest, then a study should be properly designed to ensure appropriate data are collected, in the appropriate manner.

A final point is that the photo-ID database is of Hector’s dolphins with identifying marks. Marks are accumulated throughout a dolphin’s life; hence older animals are likely to be over-represented in the population of marked dolphins. It is undetermined how accurate survival estimated from marked individuals of the Hector’s dolphin population around Banks Peninsula can be generalised to the wider population.

5. MANAGEMENT IMPLICATIONS

Spatio-temporal changes in survey effort may affect survival probabilities estimated from CJS mark-recapture models. Gormley et al. (2012) did not provide such details on the survey effort for the data used in their research, although it is clear from other publications that substantial changes in the spatial distribution of survey effort have occurred over time. In particular, pre-1991, there was very little survey effort outside Akaroa Harbour and substantially greater effort outside Akaroa Harbour from 1991 onwards. This change in survey effort largely coincides with the time periods used by Gormley et al. (2012) to represent pre- and post-sanctuary establishment periods.

Furthermore, the pre-sanctuary survival provided by Gormley et al. (2012) is very different to that estimated by Cameron et al. (1999), but it is unclear whether this is due to different modelling approaches (CJS vs. multi-state mark-recapture models), or refinements made to the database.

Therefore, it is our recommendation that the results of Gormley et al. (2012) should not be interpreted as evidence of the beneficial effects of the BPMMS on Hector’s dolphin survival due to unanswered questions surrounding the data used for the analysis, particularly with respect to pre-1990 survival estimates. Similarly, we do not recommend the estimates provided in this report should be used for management purposes because we cannot validate the data sourced from DuFresne (2004).

6. ACKNOWLEDGMENTS

We would like to thank Sam DuFresne (Independent Researcher), Andrew Gormley (Landcare Research New Zealand Ltd) for their cooperation and willingness to discuss their PhD work. We also thank the Aquatic Environment Working Group for reviewing preliminary outputs of this reanalysis. This work was completed under Fisheries New Zealand Project SEA2019-22.

7. REFERENCES

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control 19*(6): 716–723. https://doi.org/10.1109/TAC.1974.1100705

Baker, C.S.; Boren, L.; Childerhouse, S.; Constantine, R.; van Helden, A.; Lundquist, D.; Rayment, W.; Rolfe, J.R. (2019). Conservation status of New Zealand marine mammals, 2019. *New Zealand Threat Classification Series 29*. Department of Conservation, Wellington. 18 p.

Bräger, S.; Dawson, S.; Slooten, E.; Smith, S.; Stone, G.; Yoshinaga, A. (2002). Site fidelity and along-shore range in Hector's dolphin, an endangered marine dolphin from New Zealand. *Biological Conservation 108(3)*: 281–287. https://doi.org/10.1016/S0006-3207(02)00124-6

Cameron, C.; Barker, R.; Fletcher, D.; Slooten, E.; Dawson, S. (1999). Modelling survival of Hector's dolphins around Banks Peninsula, New Zealand. *Journal of Agricultural, Biological and Environmental Statistics 4(2)*: 126–135. https://doi.org/10.2307/1400593

Cormack, R.M. (1964). Estimates of survival from the sighting of marked animals. *Biometrika 51(3–4)*: 429–438. https://doi.org/10.1093/biomet/51.3-4.429

Davies, N.M.; Bian, R.; Starr, P.; Lallemand, P.; Gilbert, D.; McKenzie, J. (2008). Risk analysis for Hector's dolphin and Maui's dolphin subpopulations to commercial set net fishing using a temporal–spatial age–structured model. (Unpublished report prepared for IPA2006/05 and held by Fisheries New Zealand, Wellington.)

Dawson, S.M. (1991). Incidental Catch of Hector's Dolphin in Inshore Gillnets. *Marine Mammal Science 7(3)*: 283–295. https://doi.org/10.1111/j.1748-7692.1991.tb00103.x

Dawson, S.M.; Slooten, E.; Fresne, D.; Wade, P.R.; Clement, D. (2004). Small-boat surveys for coastal dolphins: line-transect surveys of Hector's dolphins (*Cephalorynchus hectori*). *Fisheries Bulletin 102(3)*: 441–451.

DuFresne, S. (2004). Conservation biology of Hector's dolphin. (PhD thesis held by University of Otago, Dunedin.)

Fisheries New Zealand (2018). Fisheries Assessment Plenary, May 2018: stock assessments and stock status. Volume 3: Pipi to Yellow-eyed mullet. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 660 p. Retrieved from https://www.mpi.govt.nz/dmsdocument/18337-fisheries-assessment-plenary-may-2017-volume-3-pipi-to-yellow-eyed-mullet

Fletcher, D.J. (1994). A mark-recapture model in which sightings probability depends on the number of sightings on the previous occasion. pp. 105–110. *In*: Fletcher, D.J.; Manly, B.F.J. (Eds.), *Statistics in Ecology and Environmental Monitoring*. University of Otago Press.

Francis, R.I.C.C.; Sagar, P.M. (2012). Modelling the effect of fishing on southern Buller's albatross using a 60-year dataset. *New Zealand Journal of Zoology 39(1)*: 3–17. https://doi.org/10.1080/03014223.2011.600766

Gelman, A.; Hwang, J.; Vehtari, A. (2014). Understanding predictive information criteria for Bayesian models. *Statistics and Computing 24*(6): 997–1016. https://doi.org/10.1007/s11222-013-9416-2

Gormley, A.M. (2009). Population modelling of Hector's dolphins. (PhD thesis held by University of Otago, Dunedin).

Gormley, A.M.; Dawson, S.; Slooten, E.; Bräger, S. (2005). Capture-recapture estimates of Hector's dolphin abundance at Banks Peninsula, New Zealand. *Marine Mammal Science 21(2):* 204–216. https://doi.org/10.1111/j.1748-7692.2005.tb01224.x

Gormley, A.M.; Slooten, E.; Dawson, S.; Barker, R.J.; Rayment, W.; du Fresne, S.; Bräger, S. (2012). First evidence that marine protected areas can work for marine mammals. *Journal of Applied Ecology 49(2)*: 474–480. https://doi.org/10.1111/j.1365-2664.2012.02121.x

Kellner, K. (2019). jagsUI: A Wrapper Around 'rjags' to Streamline 'JAGS' Analyses. R package version 1.5.1

Kendall, W.L.; Nichols, J.D.; Hines, J.E. (1997). Estimating Temporary Emigration Using Capture-Recapture Data with Pollock's Robust Design. *Ecology 78(2)*: 563–578. https://doi.org/10.2307/2266030

Langtimm, C.A. (2009). Non-random Temporary Emigration and the Robust Design: Conditions for Bias at the End of a Time Series. pp. 745–761. *In*: Thomson, D.L.; Cooch, E.G.; Conroy, M.J. (Eds.), *Modeling Demographic Processes In Marked Populations* (). Boston, MA: Springer US. https://doi.org/10.1007/978-0-387-78151-8_34

Langtimm, C.A.; Beck, C.A.; Edwards, H.H.; Fick-Child, K.J.; Ackerman, B.B.; Barton, S.L.; Hartley, W.C. (2004). Survival Estimates for Florida Manatees from the Photo-Identification of Individuals. *Marine Mammal Science 20(3)*: 438–463. https://doi.org/10.1111/j.1748-7692.2004.tb01171.x

Peñaloza, C.L.; Kendall, W.L.; Langtimm, C.A. (2014). Reducing bias in survival under nonrandom temporary emigration. *Ecological Applications 24*(5): 1155–1166.

Pledger, S.; Pollock, K.H.; Norris, J.L. (2003). Open capture-recapture models with heterogeneity: I. Cormack-Jolly-Seber model. *Biometrics 59(4)*: 786–794. https://doi.org/10.1111/j.0006-341x.2003.00092.x

Plummer, M. (2012). JAGS: Just Another Gibbs Sampler. *Astrophysics Source Code Library*.

Rayment, W. (2008). Distribution and ranging of Hector's dolphins: implications for protected area design. (PhD thesis held by University of Otago, Dunedin.)

Roberts, J.; Constantine, R.; Baker, C.S. (2019). Population effects of commercial fishery and non-fishery threats on Māui dolphins (*Cephalorhynchus hectori maui*). *New Zealand Aquatic Environment and Biodiversity Report No. 215*. 18 p.

Schaub, M.; Gimenez, O.; Schmidt, B.R.; Pradel, R. (2004). Estimating Survival and Temporary Emigration in the Multistate Capture–Recapture Framework. *Ecology 85(8)*: 2107–2113. https://doi.org/10.1890/03-3110

Schofield, M.R.; Barker, R.J.; MacKenzie, D.I. (2009). Flexible hierarchical mark-recapture modelling for open populations using WinBUGS. *Environmental and Ecological Statistics 16(3)*: 396–387.

Slooten, E.; Dawson, S.M.; Lad, F. (1992). Survival Rates of Photographically Identified Hector's Dolphins from 1984 to 1988. *Marine Mammal Science 8(4)*: 327–343. https://doi.org/10.1111/j.1748-7692.1992.tb00049.x

Smith, S.L. (1992). Distribution, movements and abundance of Hector's dolphin around Banks Peninsula. (MSc thesis held by University of Canterbury, Christchurch).

Vehtari, A.; Gabry, J; Magnusson, M.; Yao, Y.; Gelman, A.; Burkner, P.C.; Goodrich, B.; Piironen, J. (2019). loo: Efficient leave-one-out cross-validation and WAIC for Bayesian models. R package version 2.2.

Watanabe, S. (2010). Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory. *Journal of Machine Learning Research 11(12)*: 3571–3594.

APPENDIX A: COMPARISON OF DATA USED IN THIS ASSESSMENT WITH GORMLEY ET AL. (2005)

The 1989–1997 portion of the data used in this assessment appears to be very similar that used by Gormley et al. (2005). Figure A.1 presents the number of unique individuals recorded in each year, and over time, and Figure A.2 presents a recreation of the abundance estimates for Hector's dolphin at Banks Peninsula using the same methods as detailed by Gormley et al. (2005), assuming constant survival during the period. The abundance estimates that are obtained applying this approach to the full time series of data used in this assessment (assuming constant survival) are also presented. The presentation of these estimates is to illustrate the data similarities; the estimates are not being presented as valid abundance estimates for the Banks Peninsula population over this timeframe.

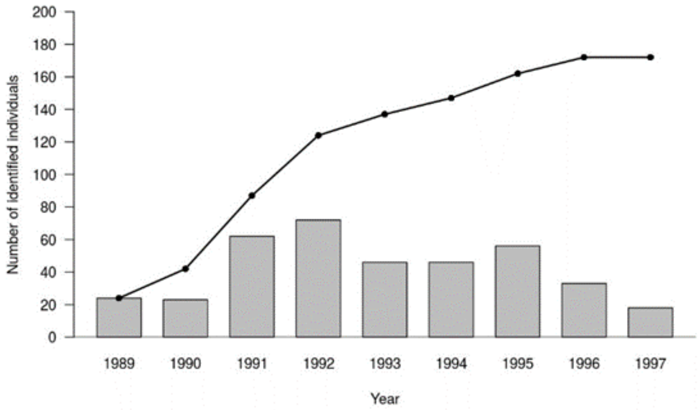


Figure A.1: Number of unique individuals recorded in each year, and cumulatively over time. Comparable with figure 3 of Gormley et al. (2005).

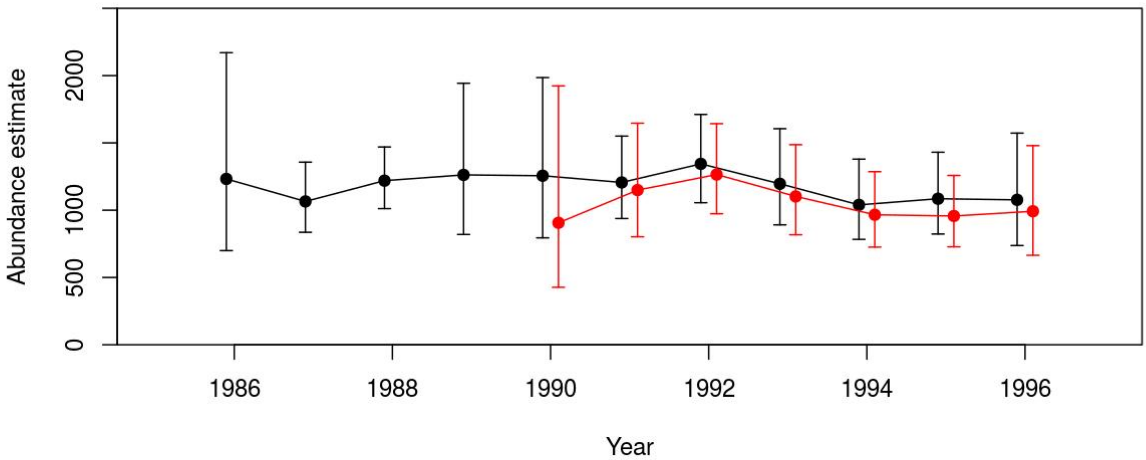


Figure A.2: Estimated abundance (and 95% confidence intervals) for Hector's dolphin at Banks Peninsula using mark-recapture methods of Gormley et al. (2005). The black time series used the full extent of the data from DuFresne (2004) and the red time series is for the subset of the data used by Gormley et al. (2005). Comparable with figure 4 of Gormley et al. (2005).

APPENDIX B: SEABIRD LIKELIHOOD CALCULATIONS

Survival s_{iy}, is the proportion of dolphins in the ith partition class that survive natural mortality to the end of year y. Potentially we can define f_t, the fraction of the annual natural mortality that occurs before time step t in each year, which gives $s_{iy}^{f_t}$. Because SEABIRD allows the user to specify annual threat-related mortality (not used by this assessment), $s_{iy} = \prod_t s_{iy}^{f_t}$ is used for annual survival in the likelihood.

Parameter estimation was by maximum likelihood. The objective function was given by:

$$-\sum_i \log\left[L\left(\mathbf{p} \mid O_i\right)\right]$$

where **p** is a vector of the free parameters, L the likelihood function and O_i the ith observation.

For Bayesian fitting the objective function was:

$$-\sum_i \log\left[L\left(\mathbf{p} \mid O_i\right)\right] - \log\left[\pi\left(\mathbf{p}\right)\right]$$

where π is the joint prior density of the parameters **p**.

Symbols used in likelihood equations for mark-recapture observations are presented in Table B.1.

Table B.1: Symbols used in SEABIRD model likelihood equations.

Symbol	Comment
b	Unique identifier
$y_{b,\mathrm{tag}}$	The year the b^{th} individual was "marked"
$y_{b,\mathrm{last}}$	The last year that the b^{th} individual was observed
O_{by}	Observed state for the b^{th} individual in year y
L_{by}	Likelihood of the observation in year y given the observation in year y–1
t_{trans}	Time within a year that the state of an individual is observed
X_{iyj}	The probability that an individual in class i in year y will be alive and in class j in the following year
$s_{\mathrm{tot},ity}$,	Survival of an individual during time step t in class i in year y
p	The proportion of the mortality that had occurred before an observation in a time step. Thus, we have subscripts like $n_{ity;p}$, to denote the number of individuals in the ith class at the time of the observation. For survival, we have $s_{\mathrm{tot},ity;p} = 1 - p + ps_{\mathrm{tot},ity}$
$r_{j,y}$	Resighting probability, the probability of seeing a marked individual in year y, given that it is alive and in the ith partition class
P_{biy}	The probability, given the observations on the individual with mark identity b up to and including year y, that this individual is in class i
$Nclass$	The number of classes

Mark-recapture observations were input as a series of observations of marked individuals, including for each individual: the identity b (a unique number), the year tagged $y_{b,\mathrm{tag}}$, the last year of observation $y_{b,\mathrm{last}}$, and the 'state' of the individual O_{by} in each year from $y_{b,\mathrm{tag}}$ to $y_{b,\mathrm{last}}$, where the 'state' indicates whether the individual was observed and, if so, which class of the partition the individual was in.

The negative log-likelihood for the individual with tag number b is given by $-\Sigma_y \log(L_{by})$, where the summation is over $y_{b,tag} < y \leq y_{b,last}$ and L_{by} is the likelihood of the observation in year y given the observation in year y–1. The likelihood calculation is a generalisation of that used in the Cormack-Jolly-Seber model (Cormack 1964). When the model partition is of size 1 (so the mark-recapture observations are simply presence/absence) the calculated likelihood is exactly the same as the Cormack-Jolly-Seber model. SEABIRD generalises this likelihood by allowing multi-state observations (partition size greater than 1).

Let X_{iyj} be the probability that an individual in class i in year y will be alive and in class j in the following year. This may be calculated by multiplying the overall survivals ($s_{\text{tot},ity}$) for each time step between the observations together with the transition probability. The equation for this depends on the relationship between the time step, t, for the mark-recapture observations, and that for the transition process, t_{trans}:

$$X_{iyj} = \begin{cases} \dfrac{s_{\text{tot},ity}}{s_{\text{tot},ity;p}} \left[\prod_{t'>t} s_{\text{tot},it'y} \right] \left[\prod_{t' \leq t_{trans}} s_{\text{tot},it',y+1} \right] \left[\prod_{t_{trans} < t' < t} s_{\text{tot},jt',y+1} \right] s_{\text{tot},jt,y+1;p} T_{y+1,ij} & \text{if } t > t_{trans} \\ \dfrac{s_{\text{tot},ity}}{s_{\text{tot},ity;p}} \left[\prod_{t < t' \leq t_{trans}} s_{\text{tot},it'y} \right] \left[\prod_{t' > t_{trans}} s_{\text{tot},jt'y} \right] \left[\prod_{t' < t} s_{\text{tot},jt',y+1} \right] s_{\text{tot},jt,y+1;p} T_{yij} & \text{if } t \leq t_{trans} \end{cases}$$

where we use the convention that 'empty' products are equal to 1 (e.g., the first product in the upper formula will be empty if t is the last time step).

To calculate the likelihoods L_{by}, we needed to define P_{biy} to be the probability, given the observations on the individual with tag number b up to and including year y, that this individual was in class i in that year. For an individual observed in class j in year y

$$P_{biy} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases}$$

If the observed class in year y+1 (i.e., $O_{b,y+1}$) is ≤ 0, then

$$P_{bj,y+1} = \begin{cases} \dfrac{\sum_{i \in O_{by}} P_{biy} X_{iyj} r_{j,y+1}}{\sum_{i \in O_{by}} P_{biy} \sum_{j' \in O_{b,y+1}} X_{iyj'} r_{j',y+1}} & \text{if } O_{b,y+1} > 0 \text{ and } j \in O_{b,y+1} \\ 0 & \text{if } O_{b,y+1} > 0 \text{ and } j \notin O_{b,y+1} \\ \dfrac{\sum_{i \in O_{by}} P_{biy} X_{iyj} \left(1 - r_{j,y+1}\right)}{1 - \sum_{i \in O_{by}} P_{biy} \sum_{j'} X_{iyj'} r_{j',y+1}} & \text{if } O_{b,y+1} = 0 \\ \sum_{i \in O_{by}} P_{biy} X_{iyj} & \text{if } O_{b,y+1} = -1 \end{cases}$$

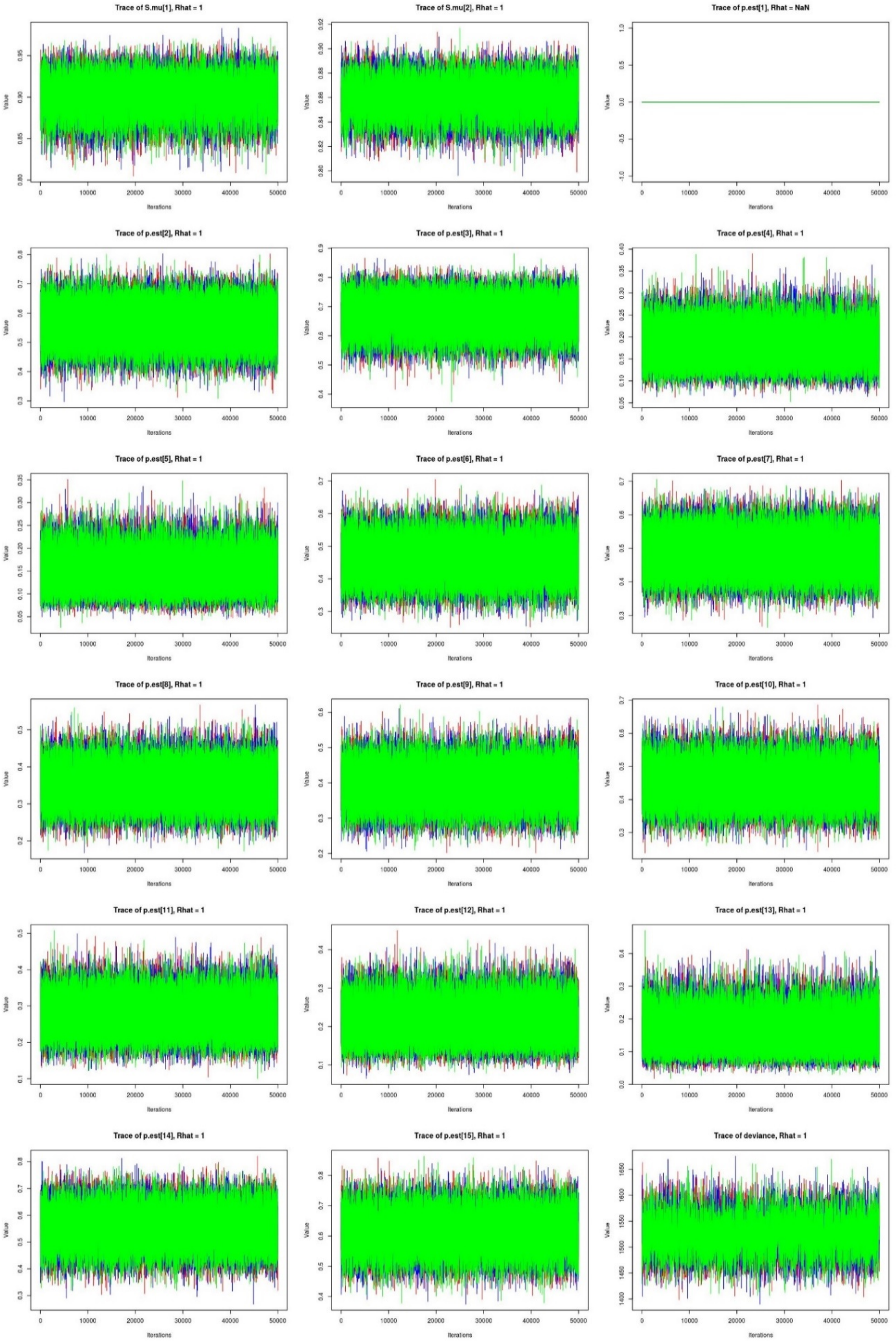
where, for $O_{by} \leq 0$ the notation $\sum_{i \in O_{by}}$ implies a sum over all classes (i.e., from 1 to *Nclass*), as does $\sum_{j'}$.

The likelihoods are calculated as:

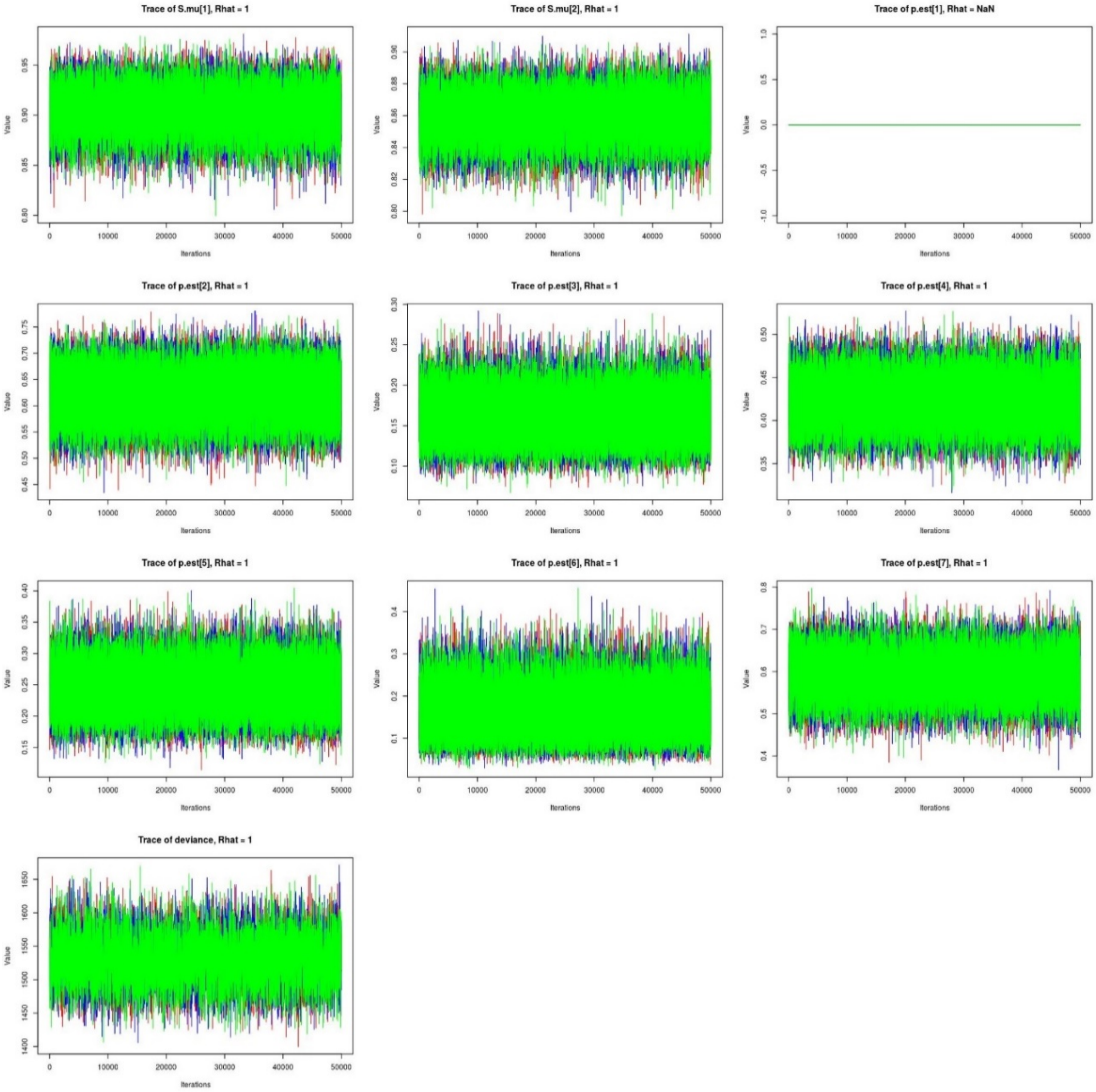
$$L_{b,y+1} = \begin{cases} \sum_{i \in O_{by}} P_{biy} \sum_{j \in O_{b,y+1}} X_{iyj} r_{j,y+1} & \text{if } O_{b,y+1} > 0 \\ \left(1 - \sum_i P_{biy}\right) + \sum_{i \in O_{by}} P_{biy} \left[1 - \sum_j X_{iyj} r_{j,y+1}\right] & \text{if } O_{b,y+1} = 0 \\ 1 & \text{if } O_{b,y+1} = -1 \end{cases}$$

APPENDIX C: TRACEPLOTS FOR JAGS ANALYSES

Model 1a



Model 2b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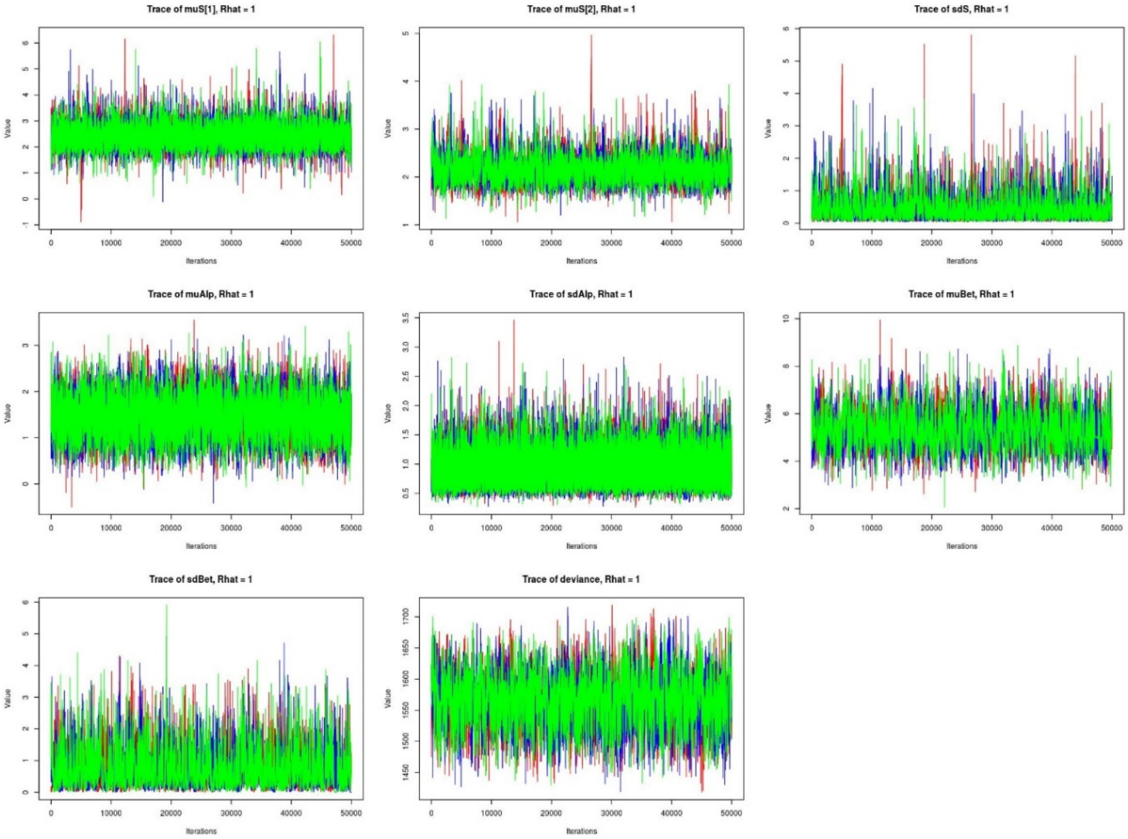
Trace of S.mu[2], Rhat = 1
Trace of p.est[1], Rhat = NaN
Trace of p.est[2], Rhat = 1
Trace of p.est[3], Rhat = 1
Trace of p.est[4], Rhat = 1
Trace of p.est[5], Rhat = 1
Trace of p.est[6], Rhat = 1
Trace of p.est[7], Rhat = 1
Trace of deviance, Rhat = 1
Value
Iterations

Model S1.p1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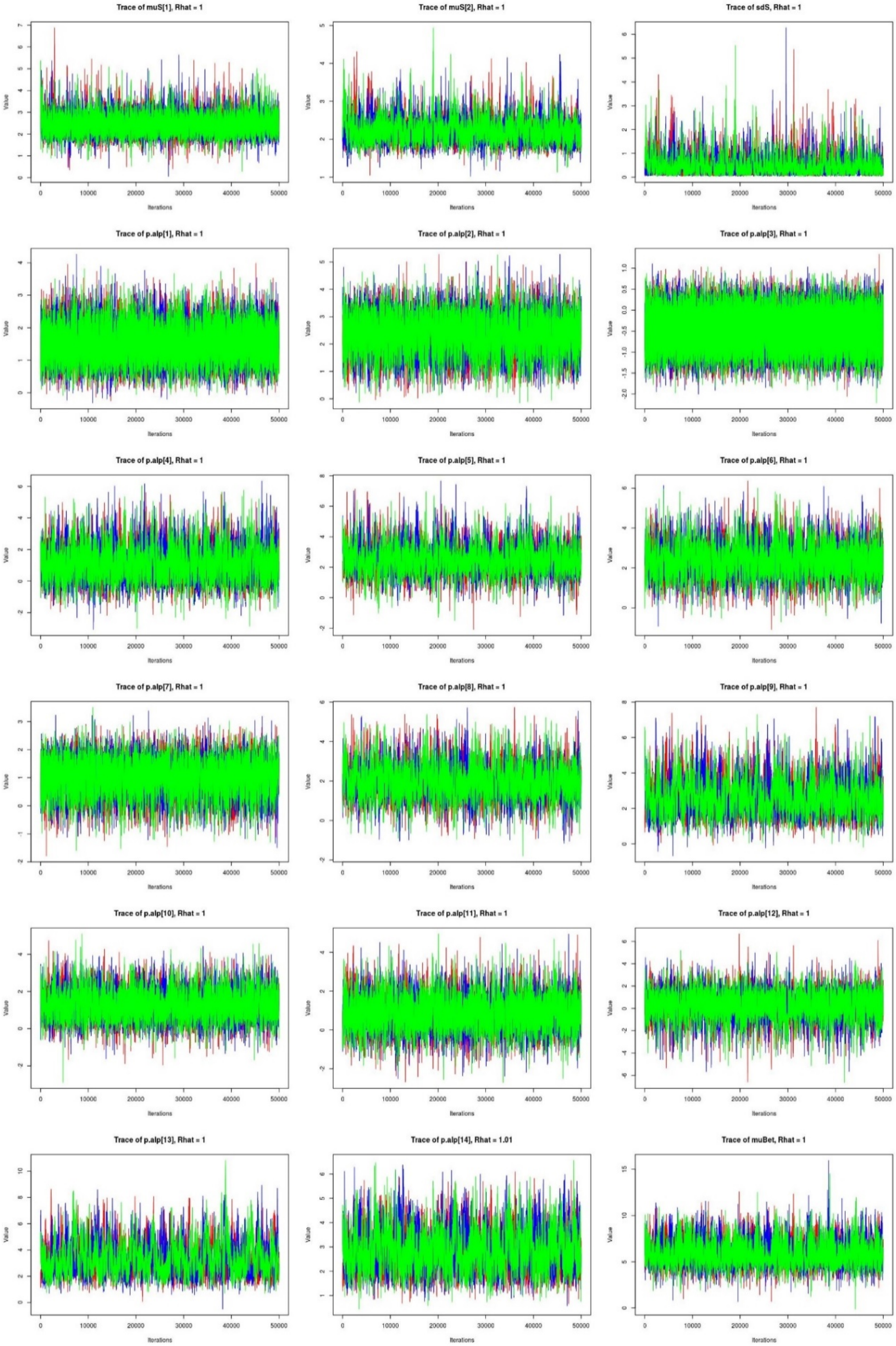
Trace of muS[2], Rhat = 1
Trace of sdS, Rhat = 1
Trace of muAlp, Rhat = 1
Trace of sdAlp, Rhat = 1
Trace of muBet, Rhat = 1
Trace of sdBet, Rhat = 1
Trace of deviance, Rhat = 1
Value
Iterations

Model S1.p2 (continued next page)



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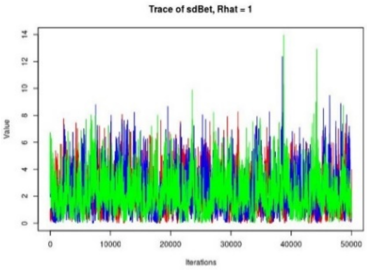
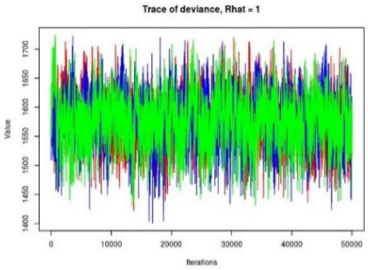
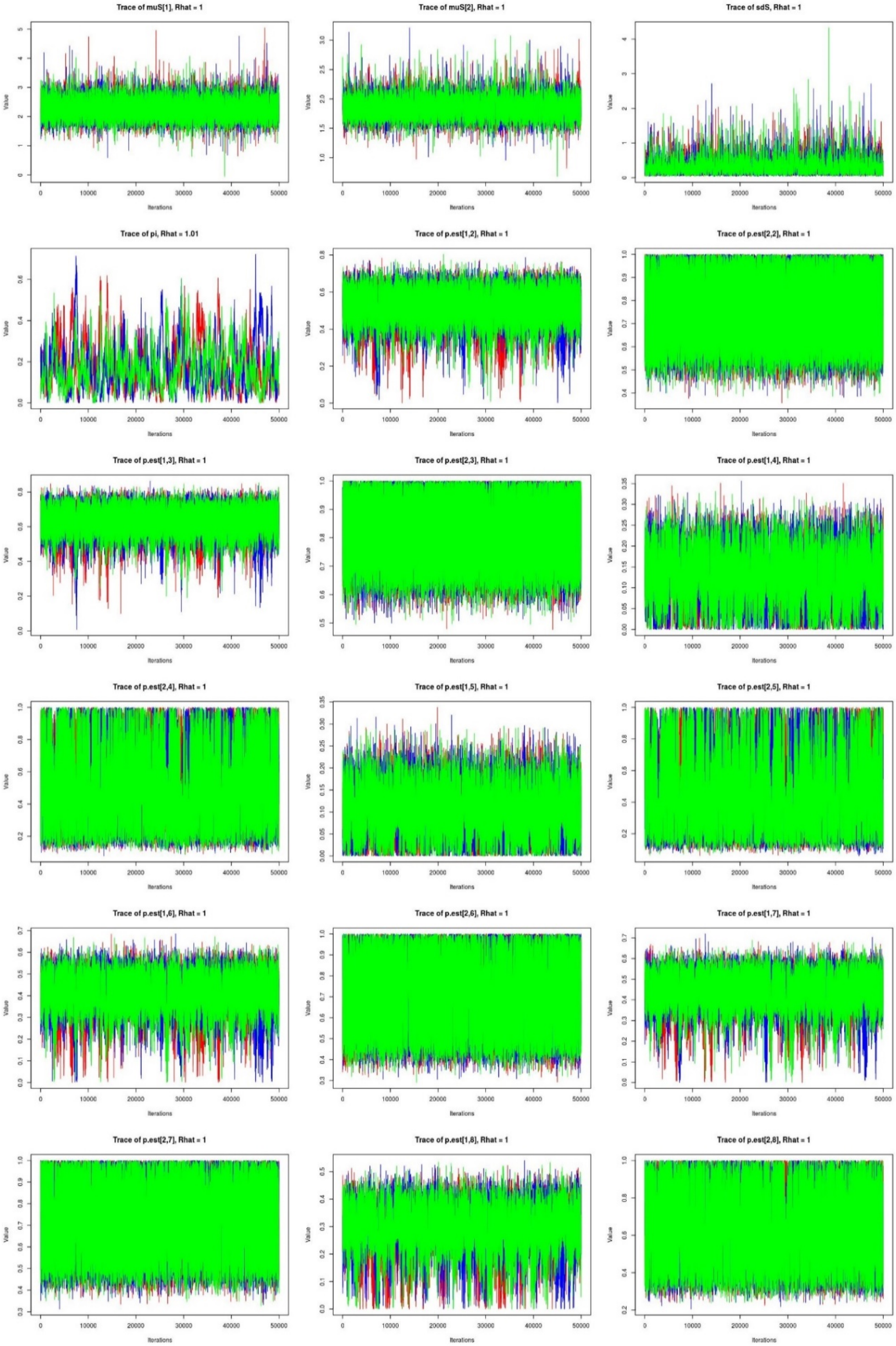
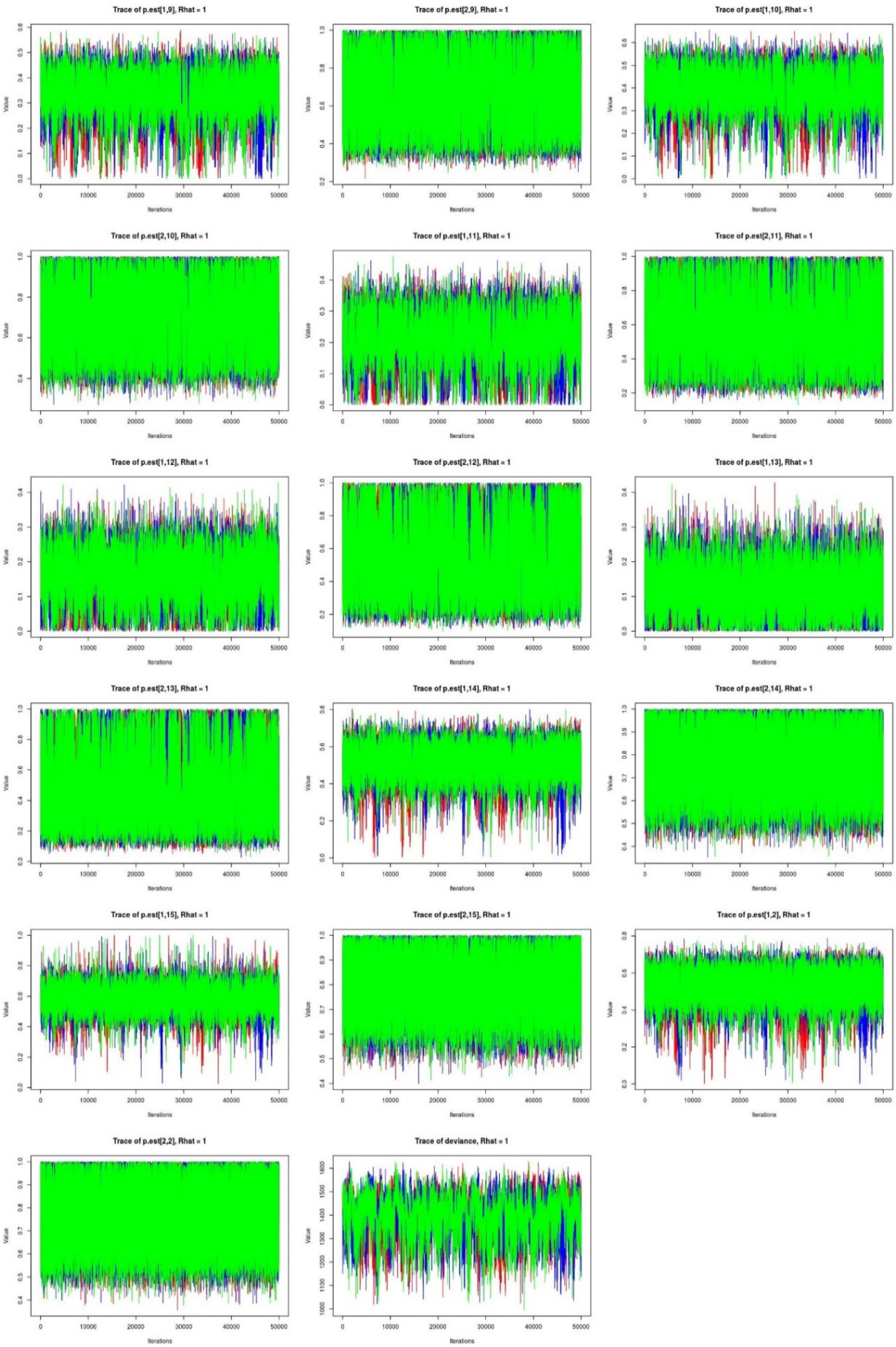




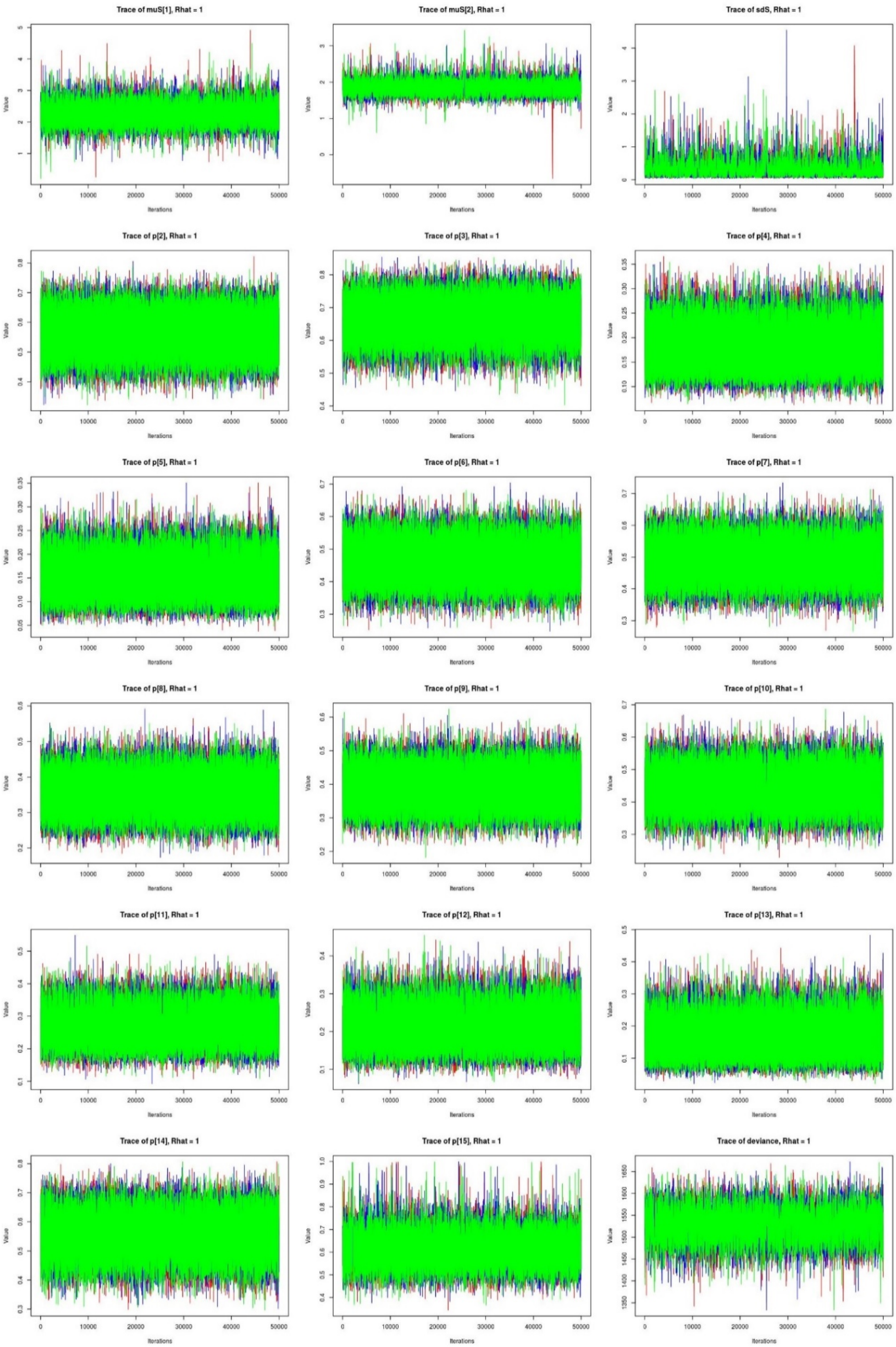
Model S1.p3 (continued next page)



Model S1.p3 — continued



Model S1.p4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Trace of p[3], Rhat = 1
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Trace of p[7], Rhat = 1
Trace of p[8], Rhat = 1
Trace of p[9], Rhat = 1
Trace of p[10], Rhat = 1
Trace of p[11], Rhat = 1
Trace of p[12], Rhat = 1
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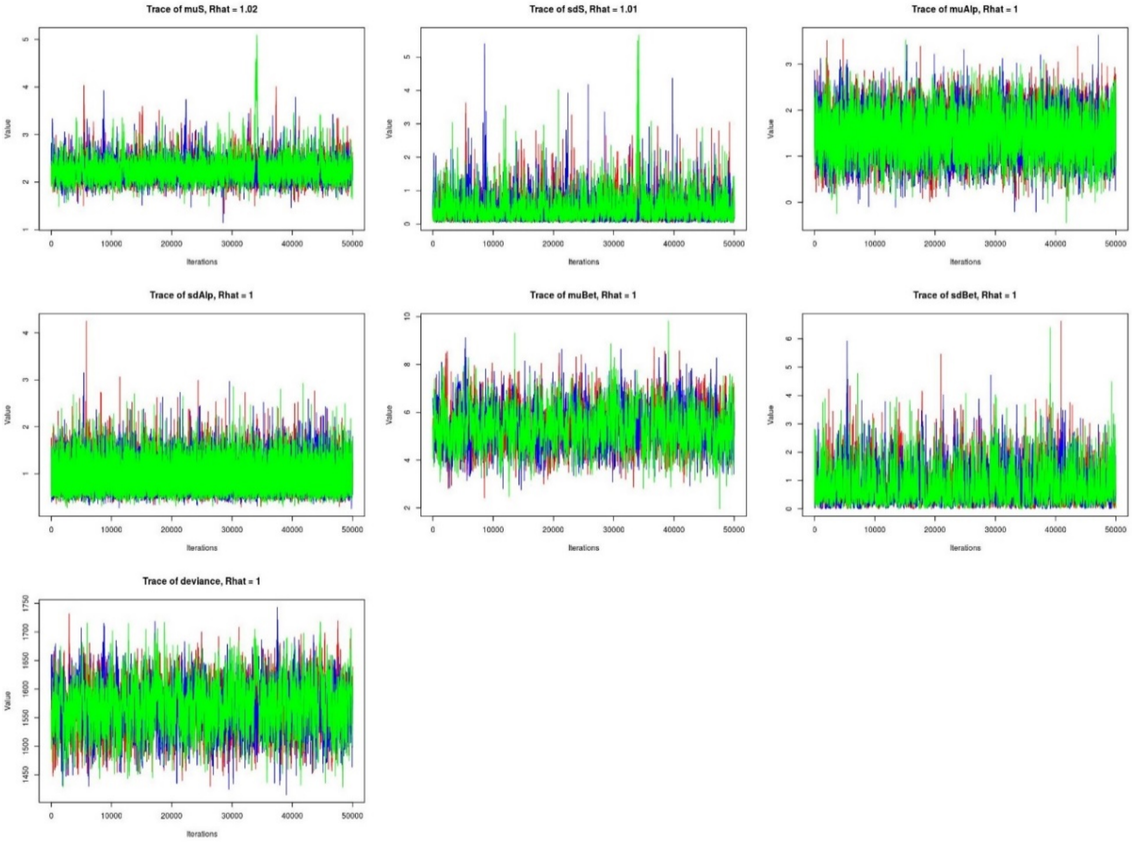
Trace of p[14], Rhat = 1
Trace of p[15], Rhat = 1
Trace of deviance, Rhat = 1

Model S2.p1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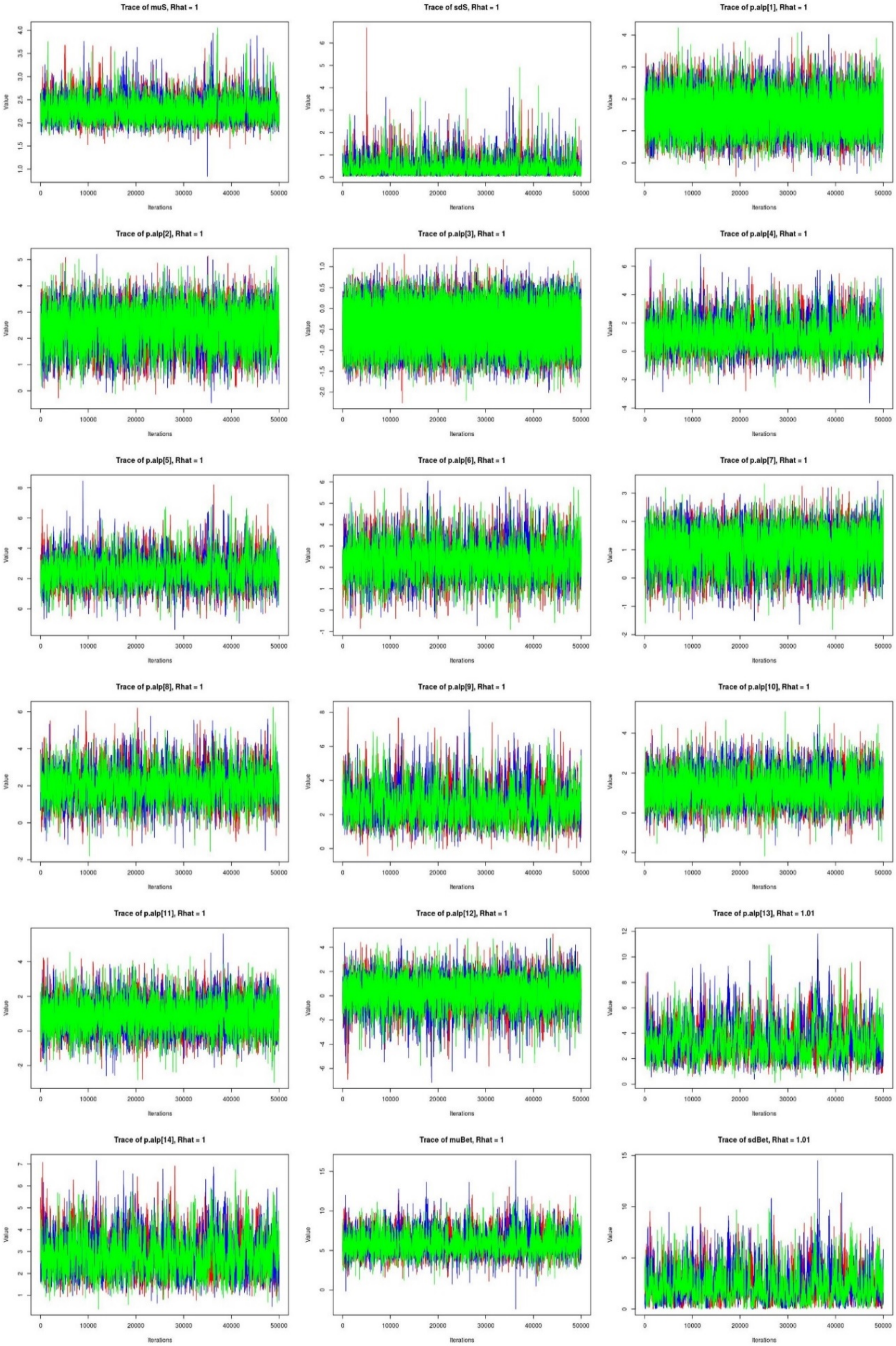
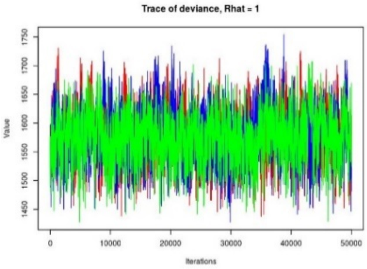
Trace of sdAlp, Rhat = 1
Trace of muBet, Rhat = 1
Trace of sdBet, Rhat = 1
Trace of deviance, Rhat = 1

Model S2.p2 (continued next page)



Model S2.p2 — continued



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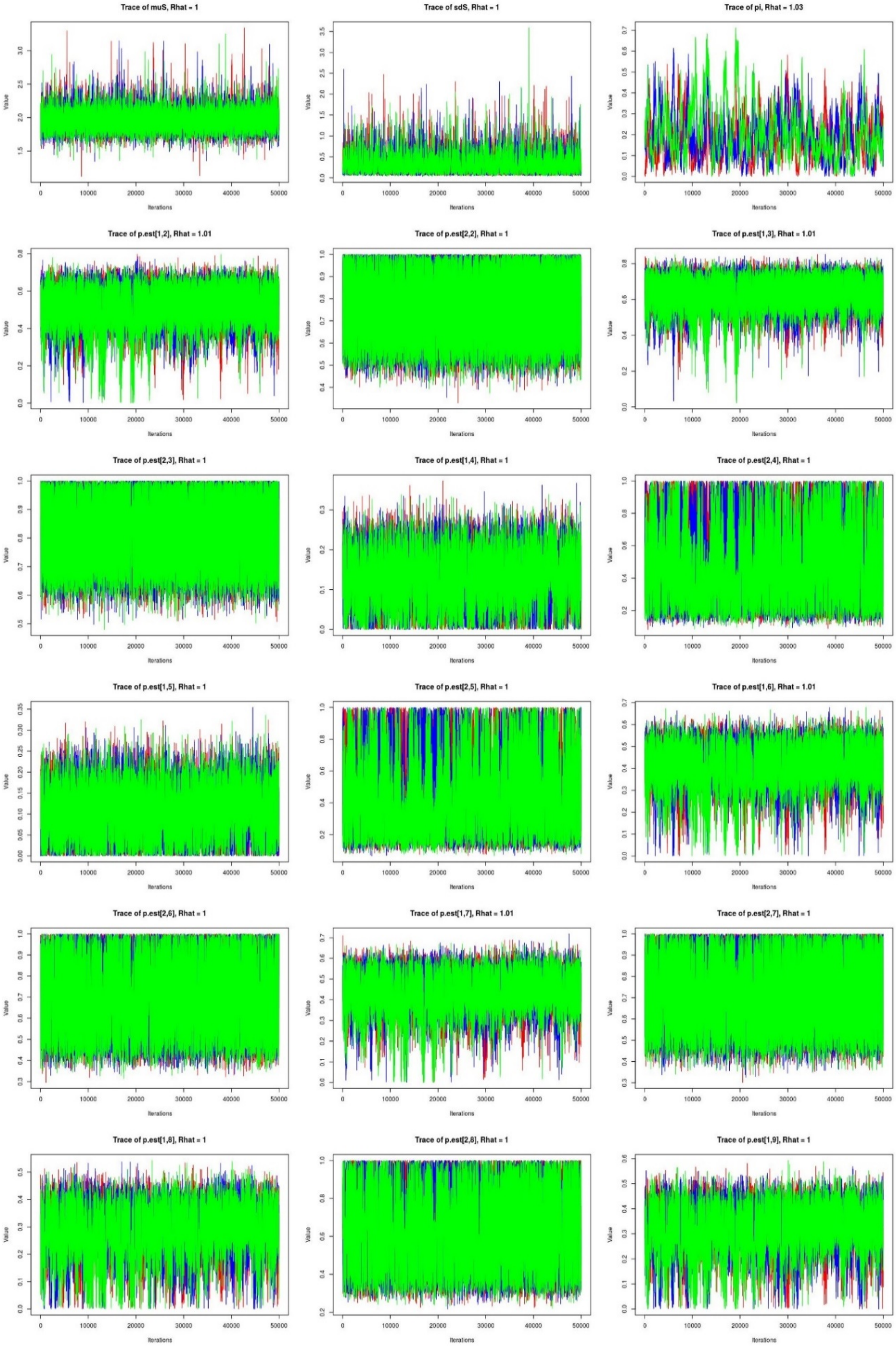

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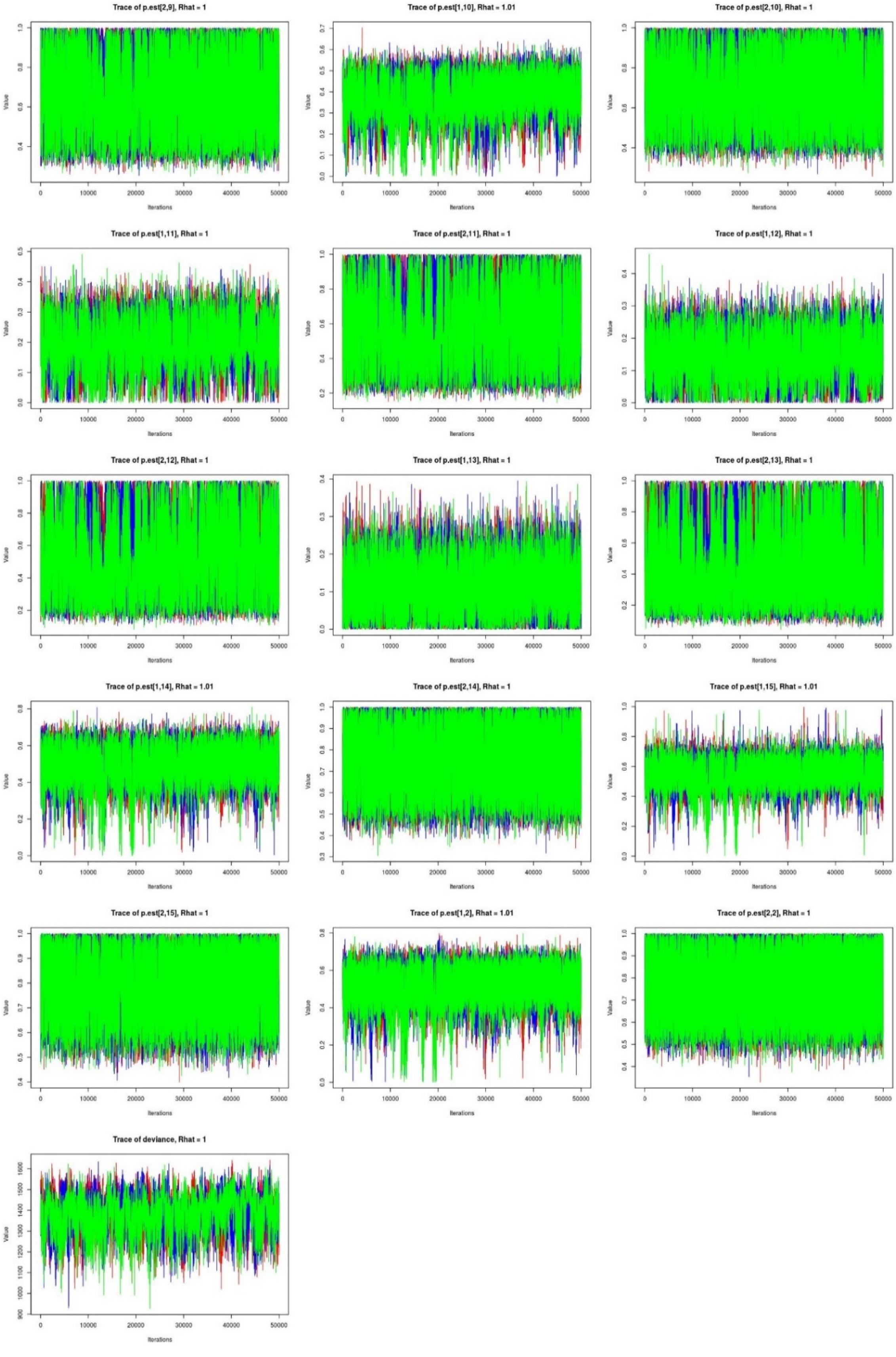
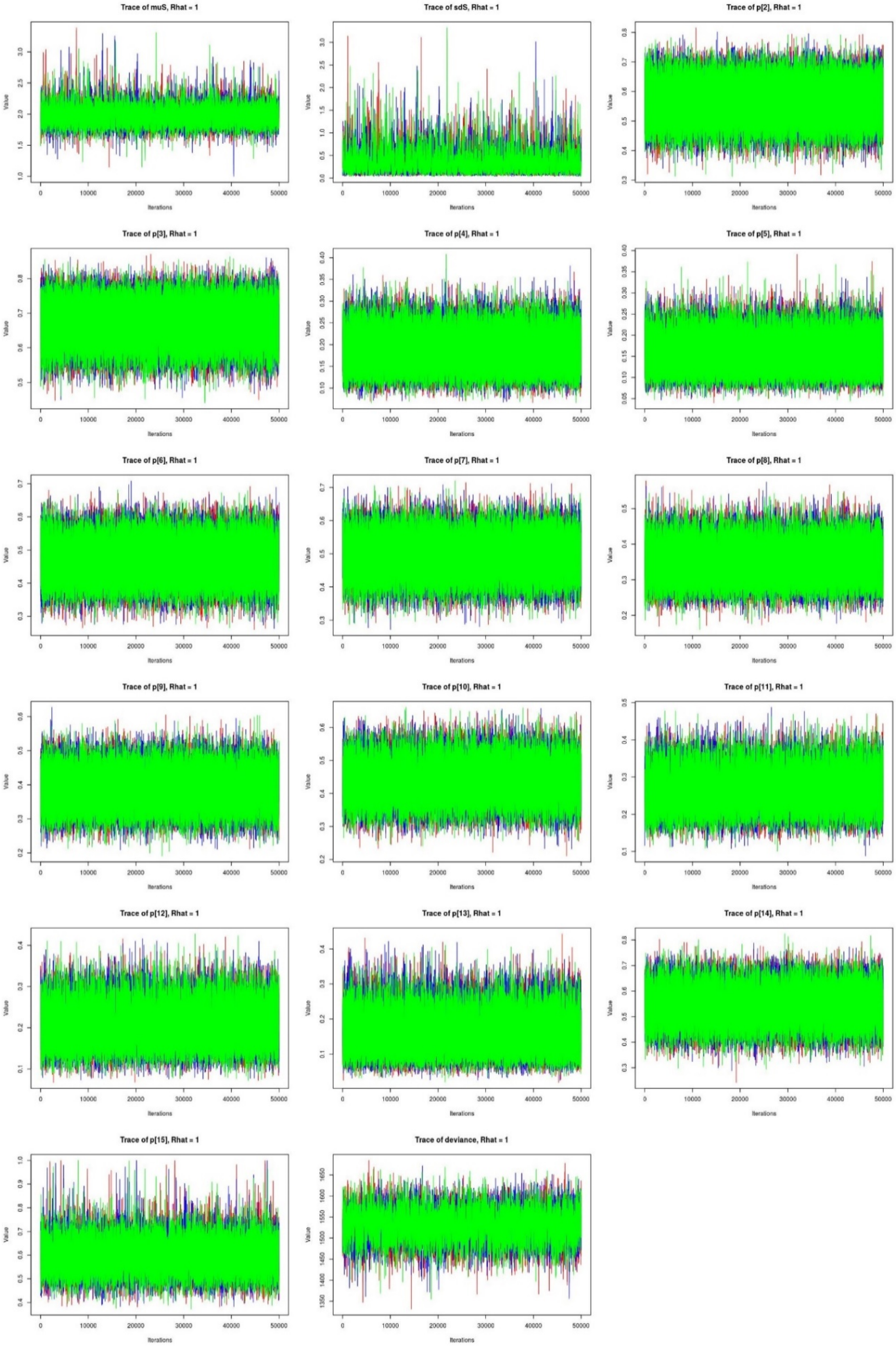


Model S2.p4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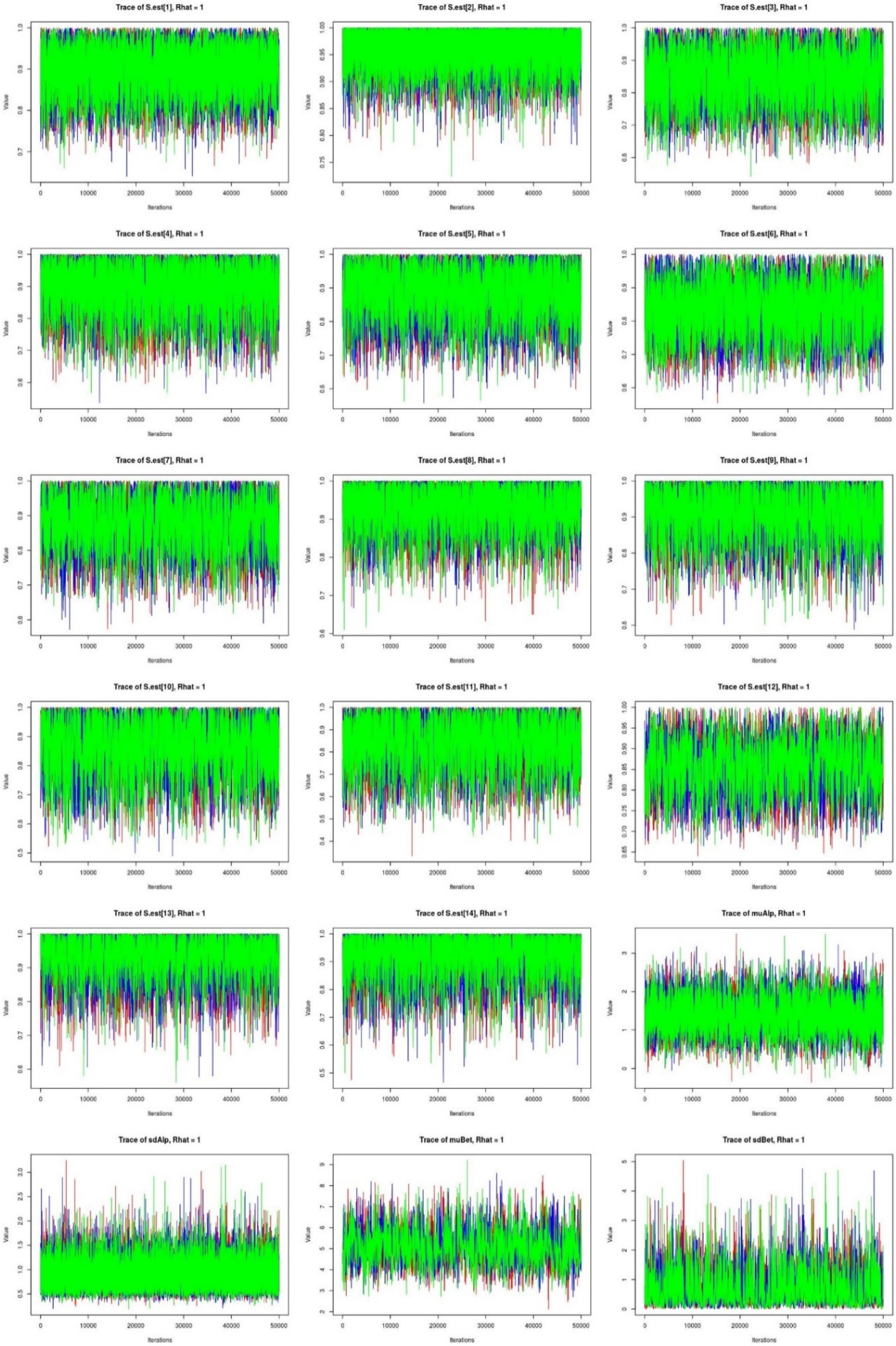
Trace of p[4], Rhat = 1
Trace of p[5], Rhat = 1
Trace of p[6], Rhat = 1
Trace of p[7], Rhat = 1
Trace of p[8], Rhat = 1
Trace of p[9], Rhat = 1
Trace of p[10], Rhat = 1
Trace of p[11], Rhat = 1
Trace of p[12], Rhat = 1
Trace of p[13], Rhat = 1
Trace of p[14], Rhat = 1
Trace of p[15], Rhat = 1
Trace of deviance, Rhat = 1
Value
Iterations

Model S3.p1 (continued next page)



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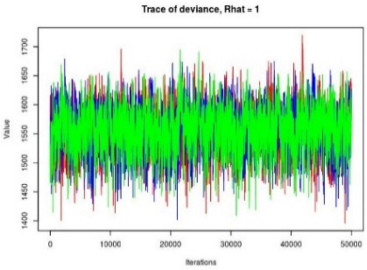

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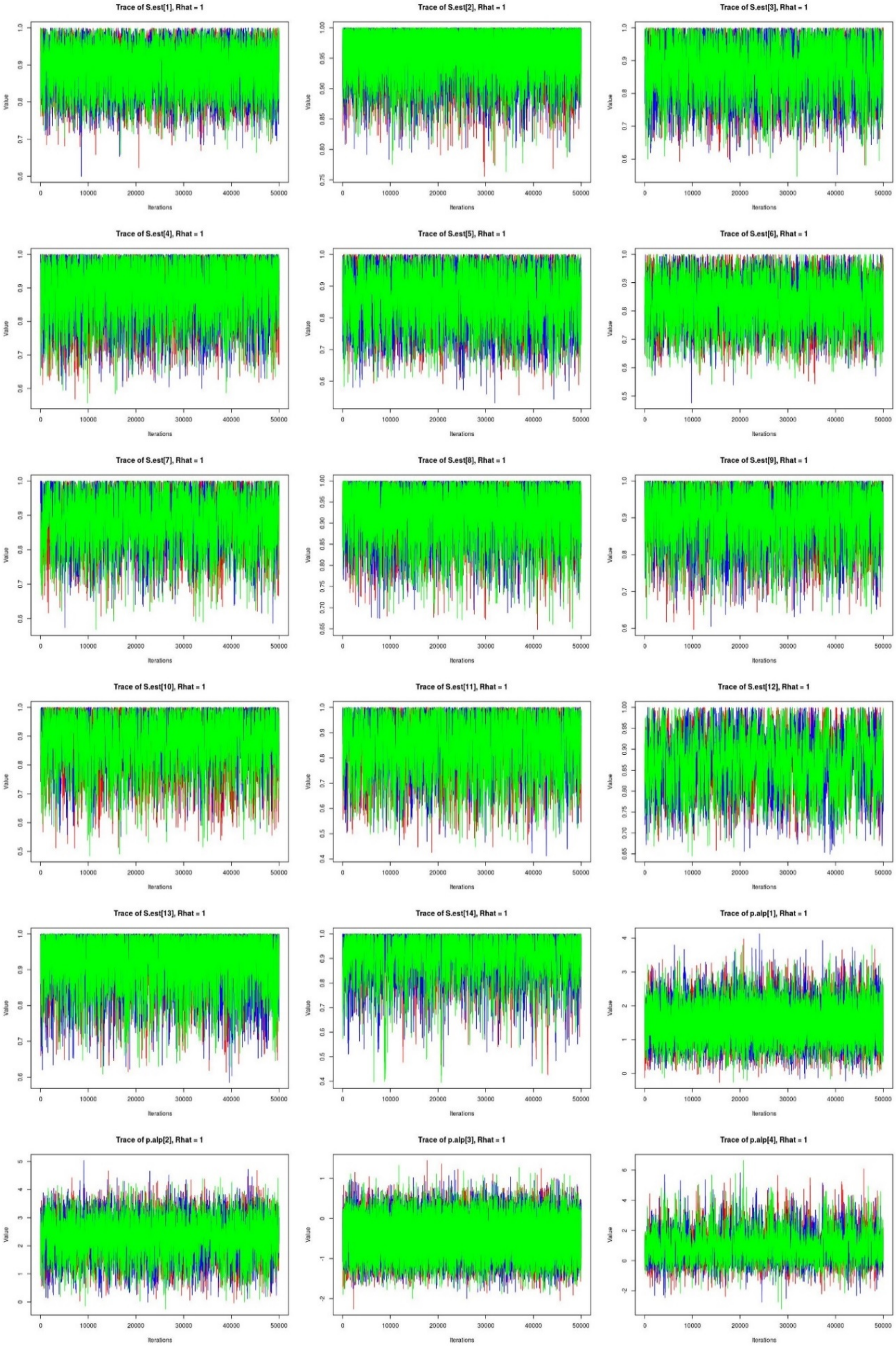

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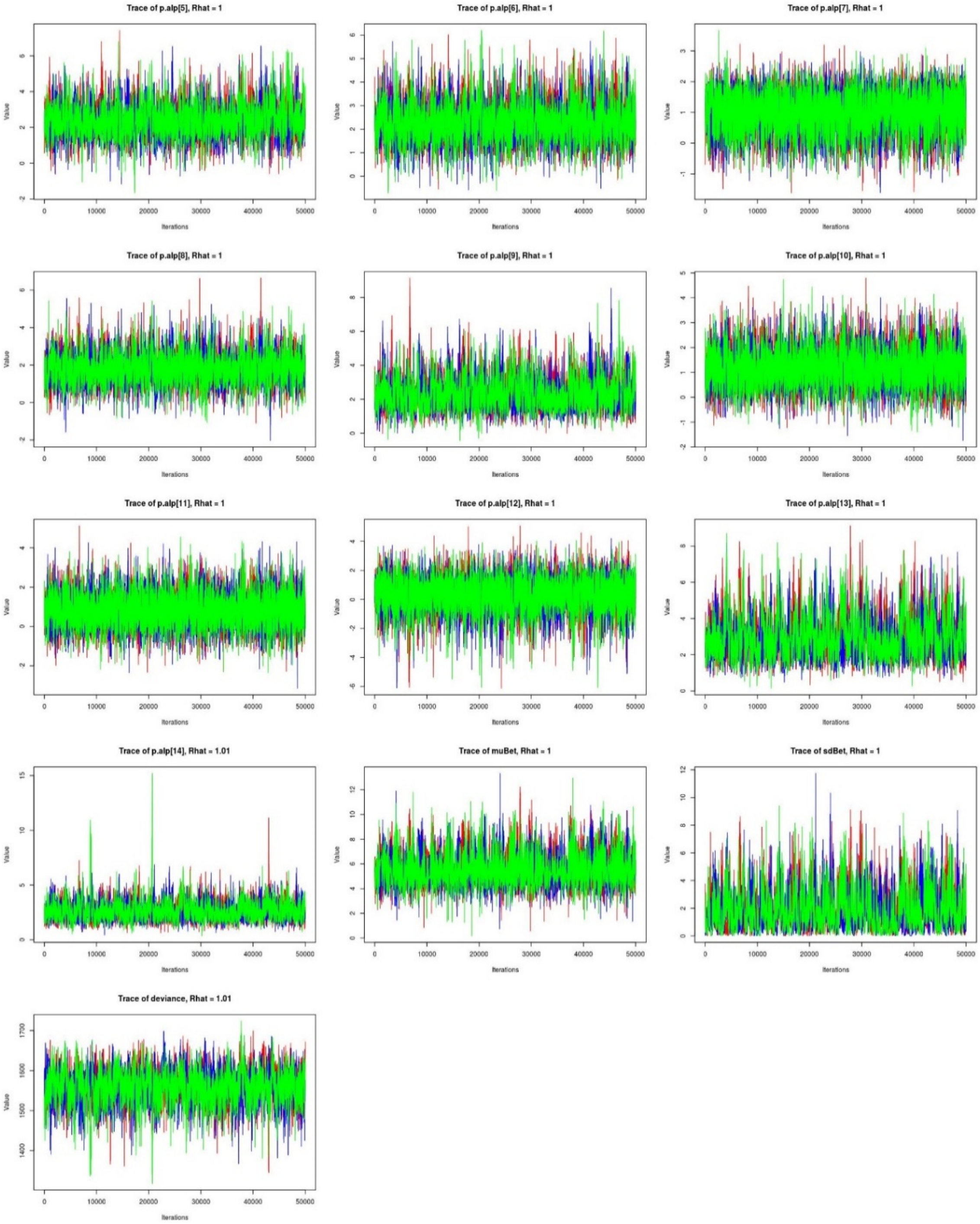

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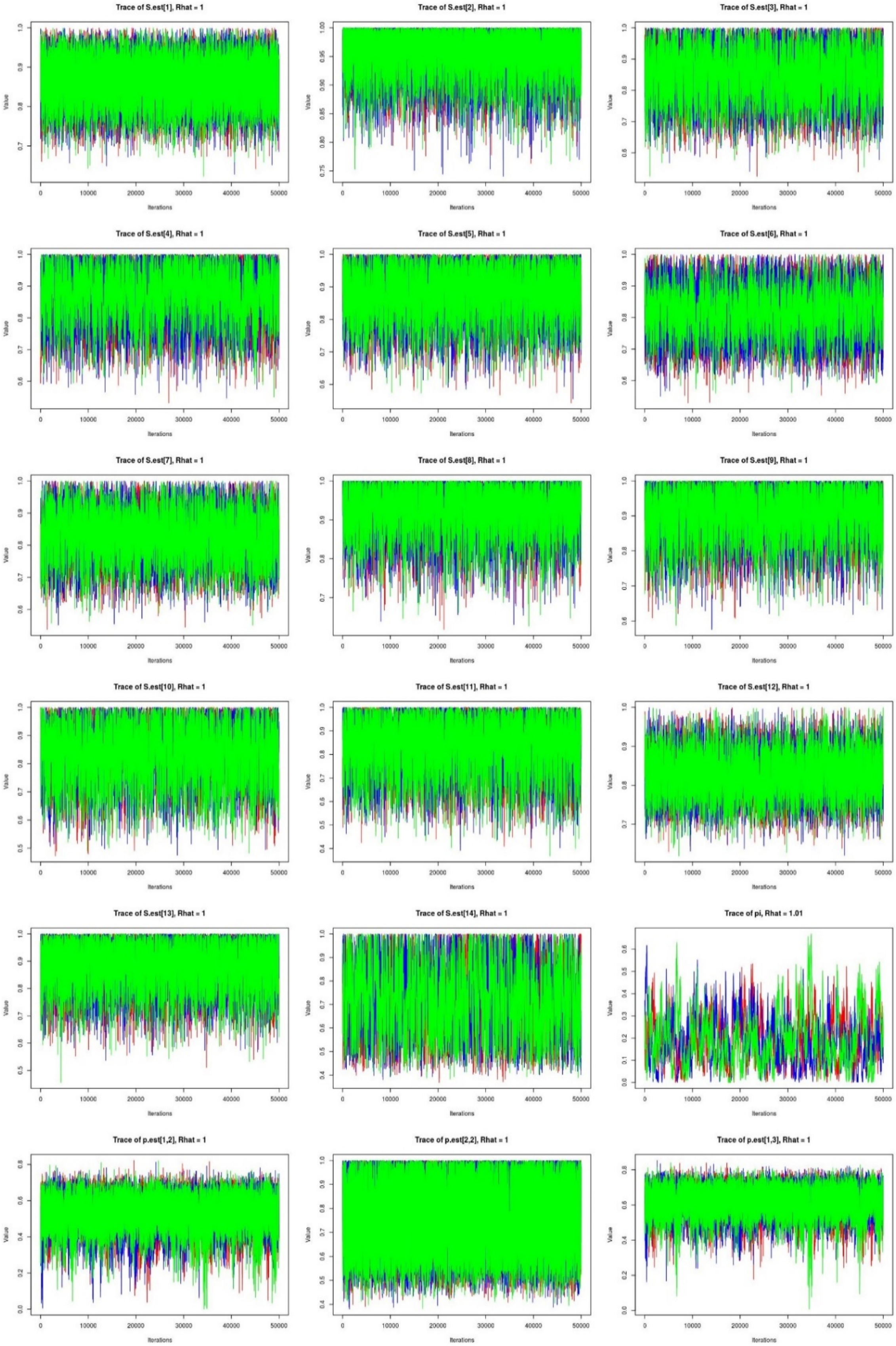

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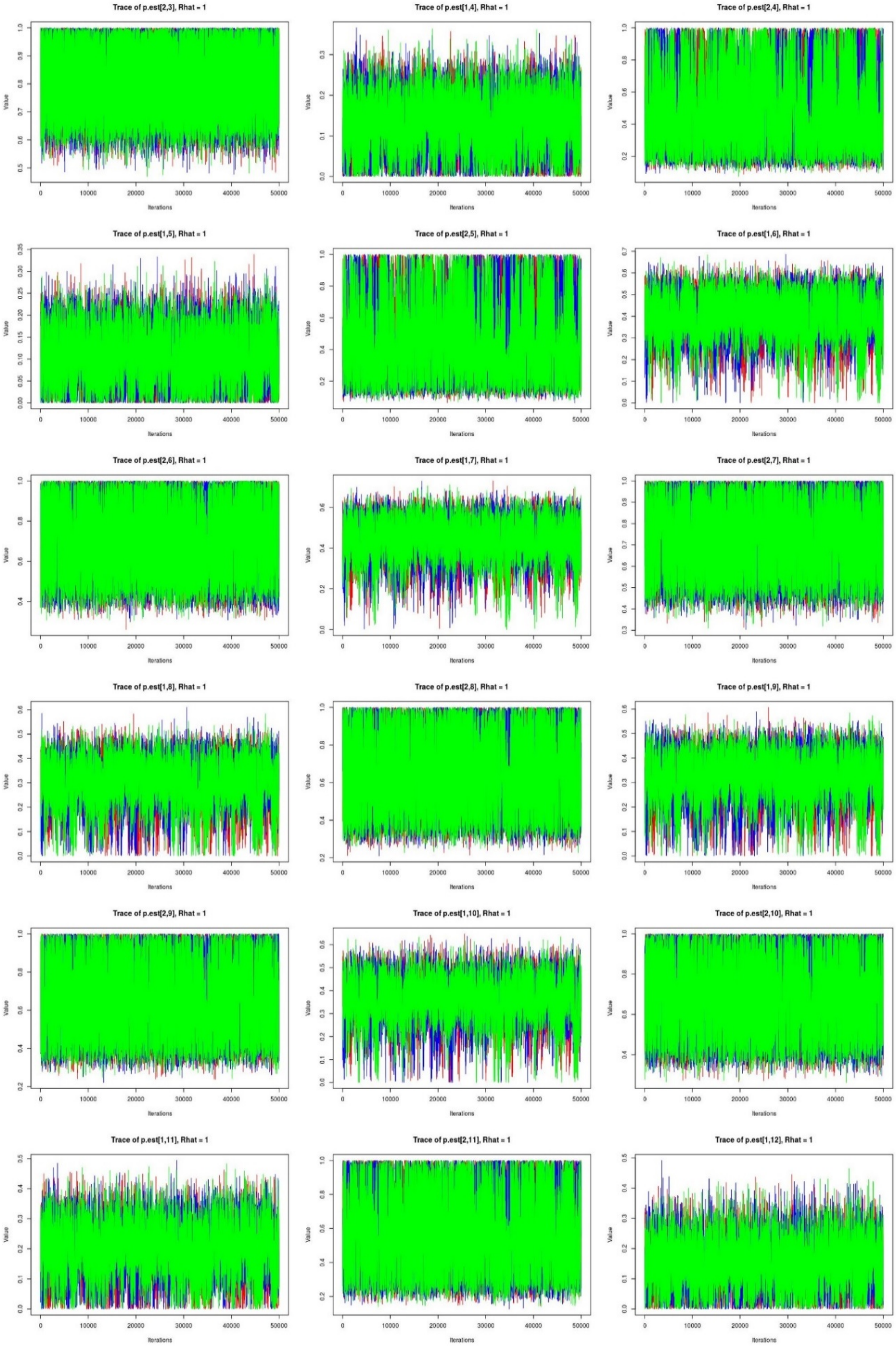

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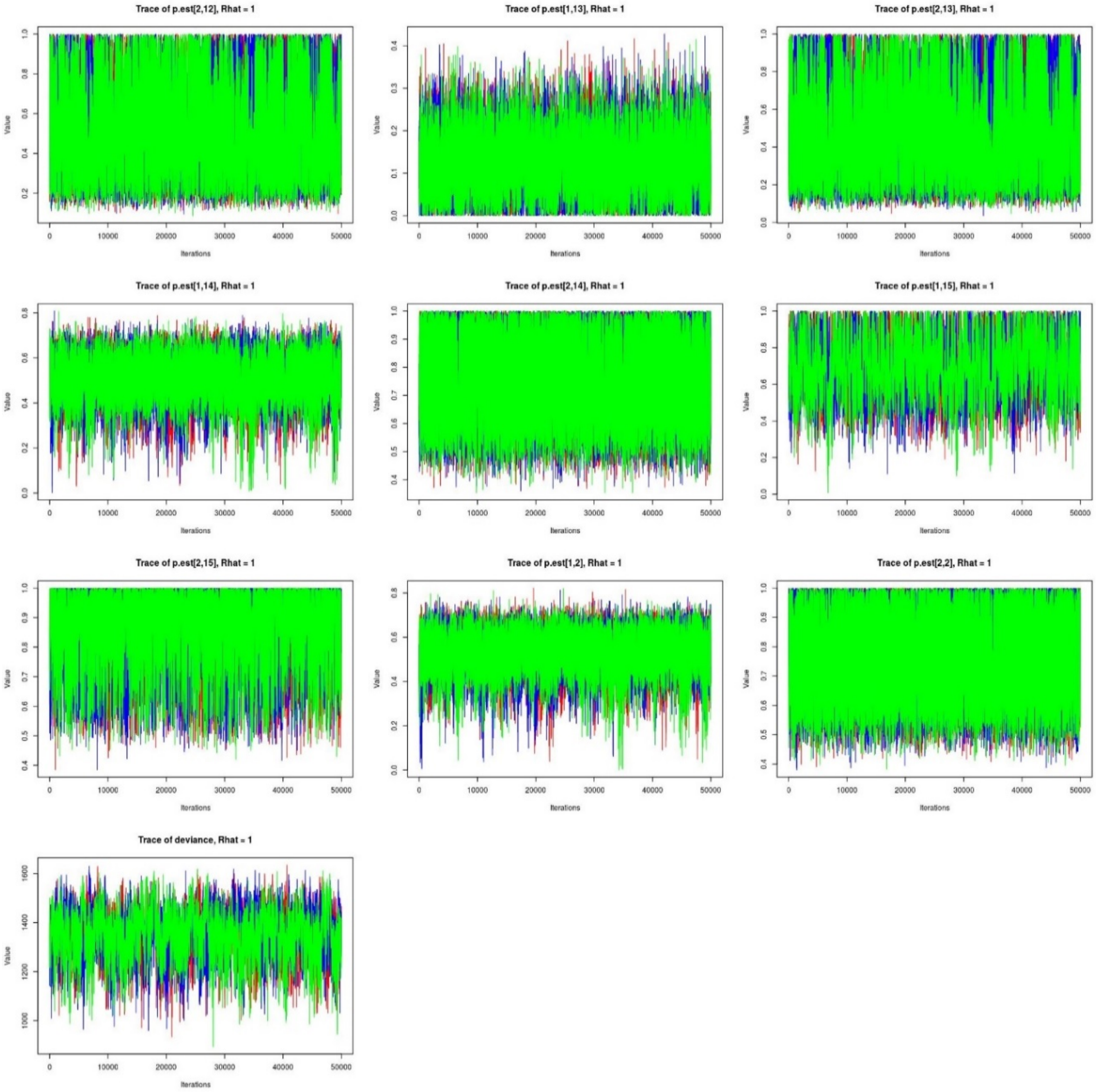

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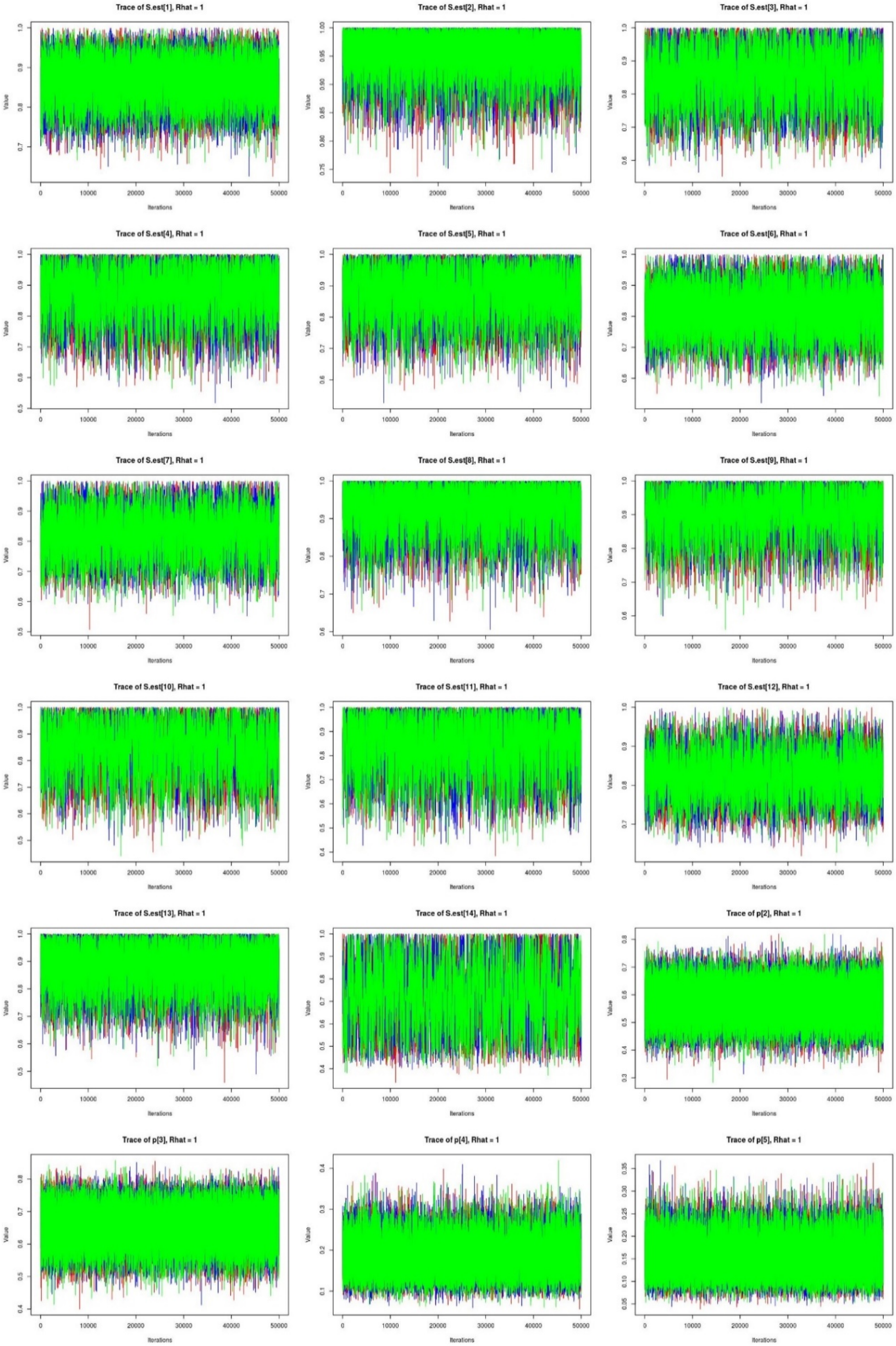
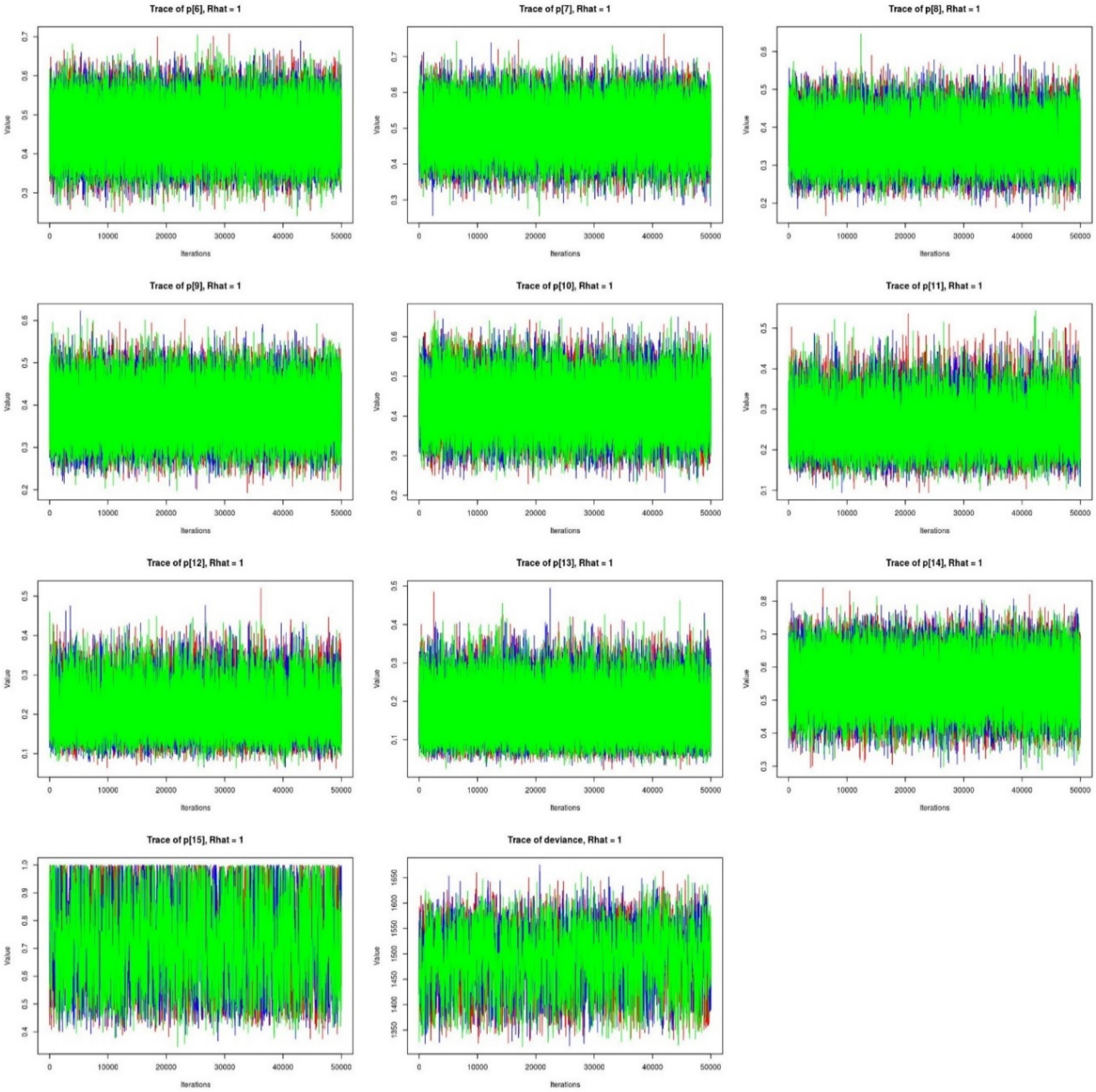
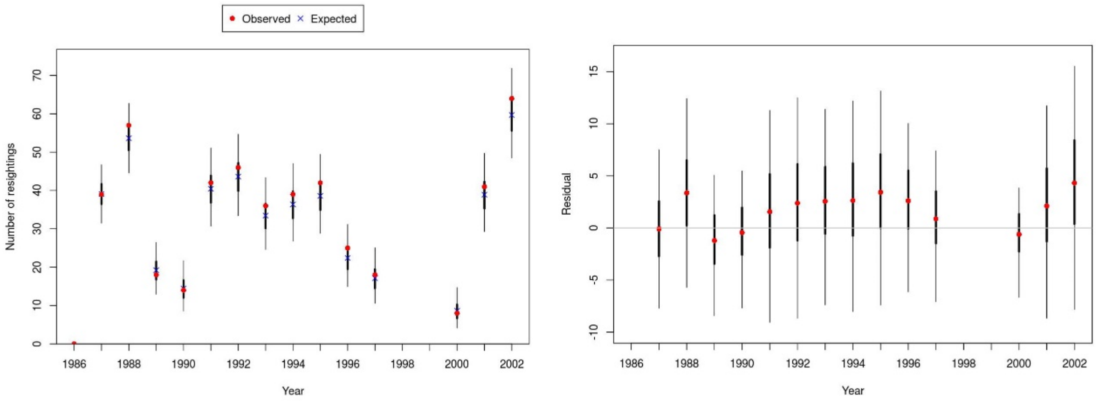


Model S3.p4 — continued

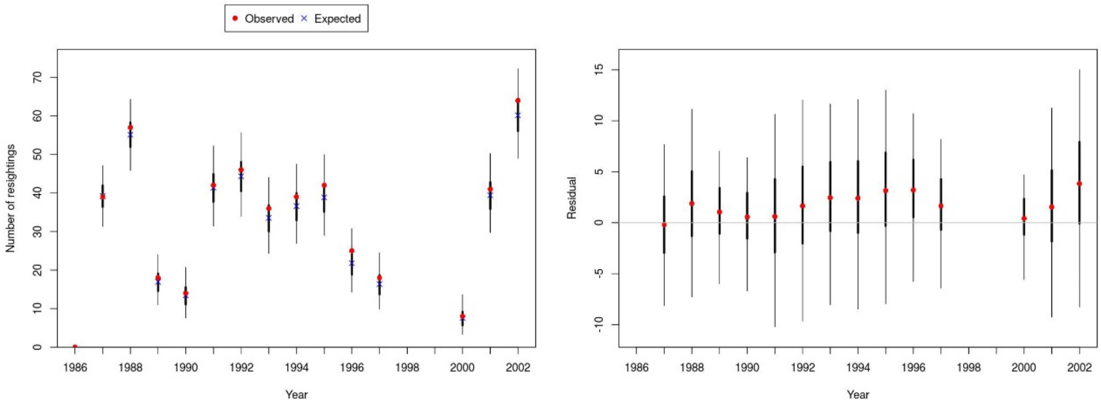


APPENDIX D: DIAGNOSTIC PLOTS FOR JAGS ANALYSES

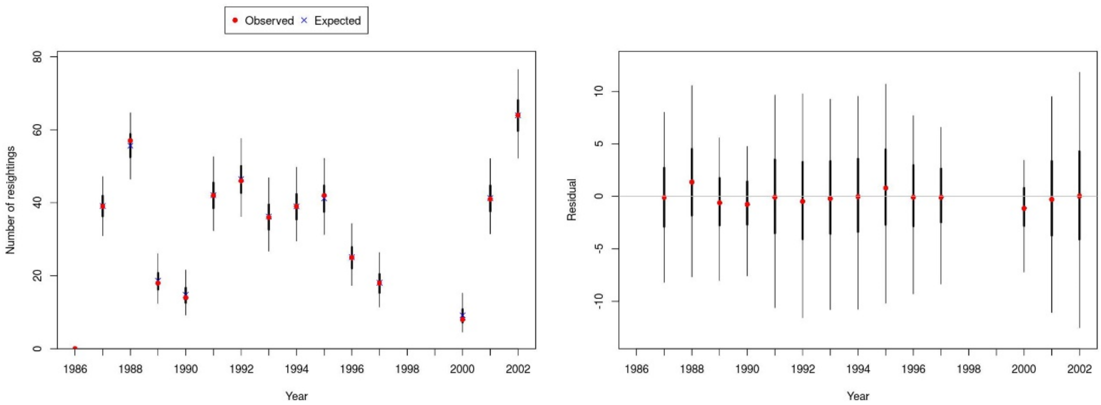
Model S1.p1: Observed and expected number of individuals resighted each year, and associated residuals.



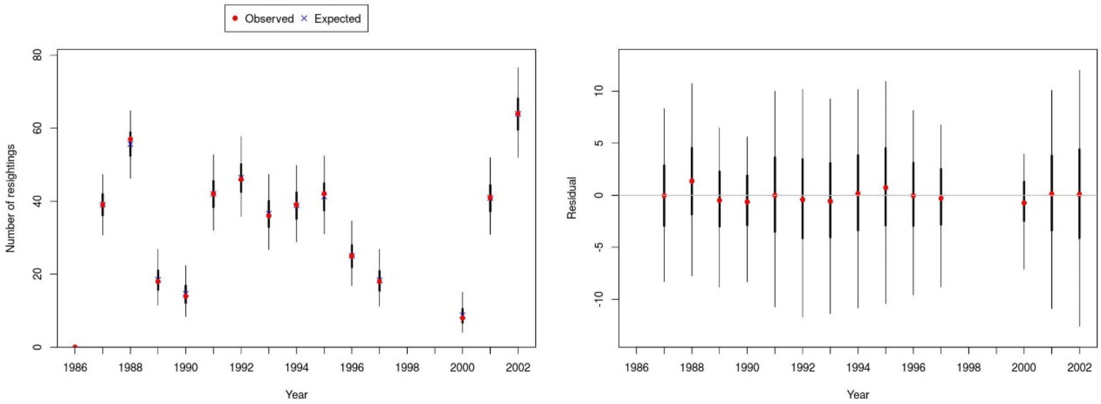
Model S1.p2: Observed and expected number of individuals resighted each year, and associated residuals.



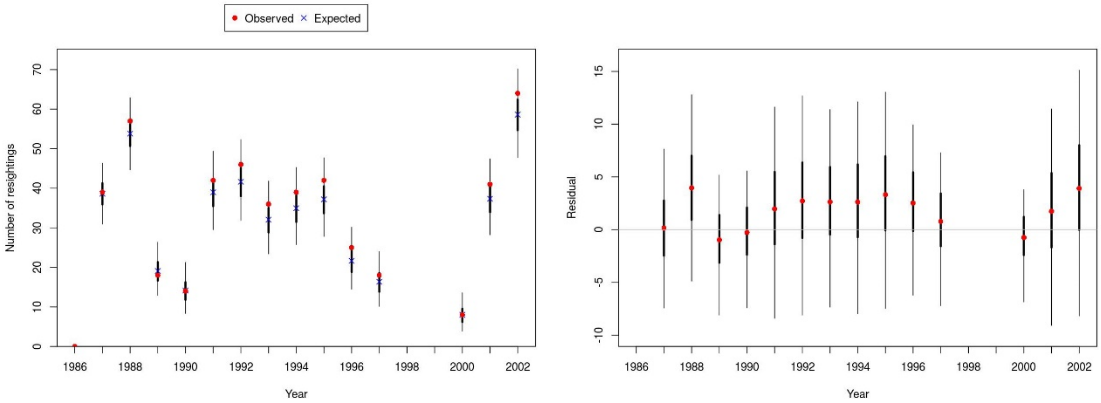
Model S1.p3: Observed and expected number of individuals resighted each year, and associated residuals.



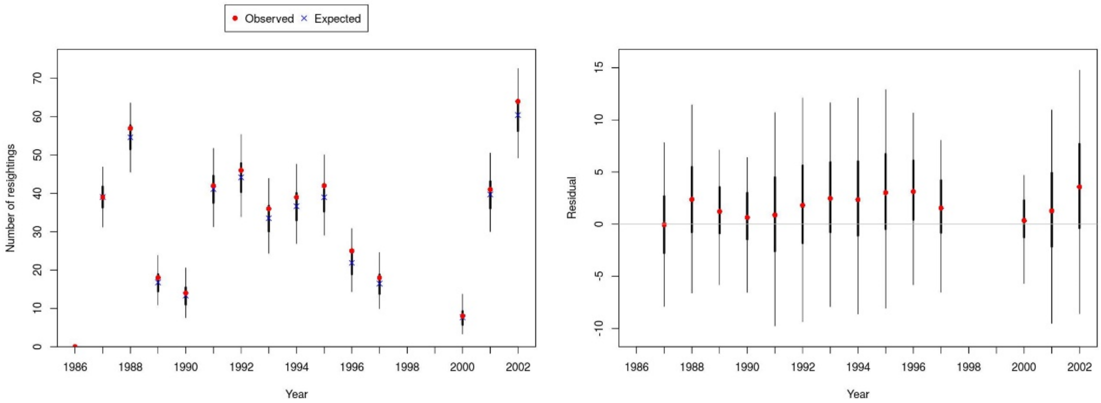
Model S1.p4: Observed and expected number of individuals resighted each year, and associated residuals.



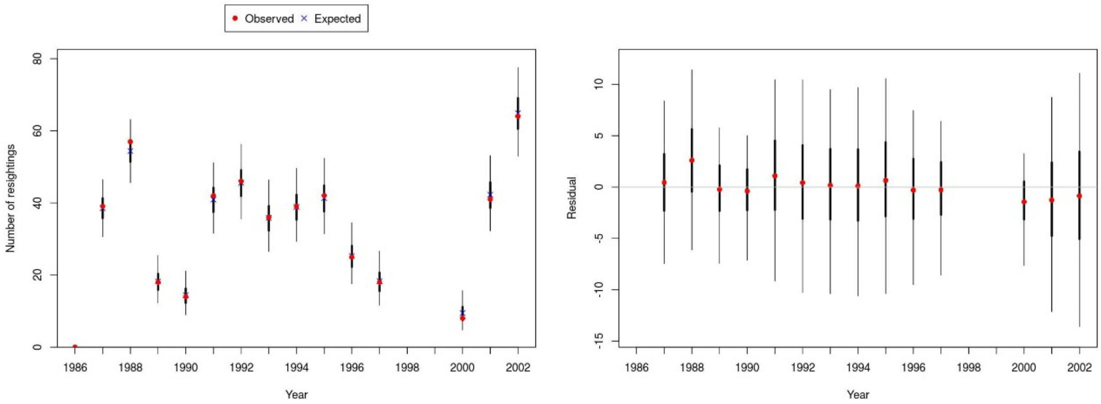
Model S2.p1: Observed and expected number of individuals resighted each year, and associated residuals.



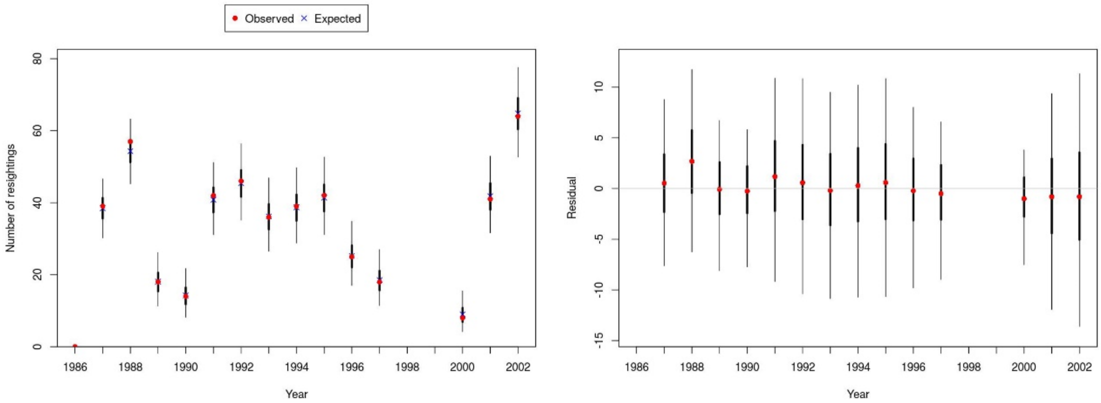
Model S2.p2: Observed and expected number of individuals resighted each year, and associated residuals.



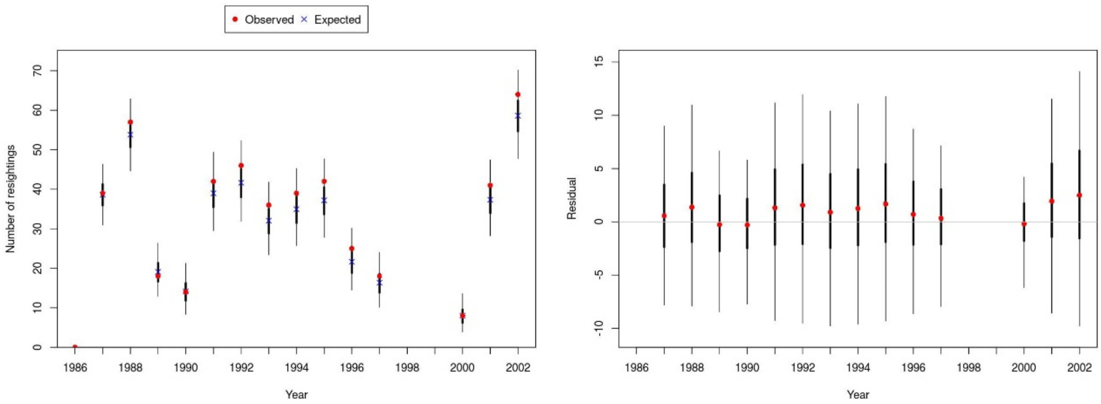
Model S2.p3: Observed and expected number of individuals resighted each year, and associated residuals.



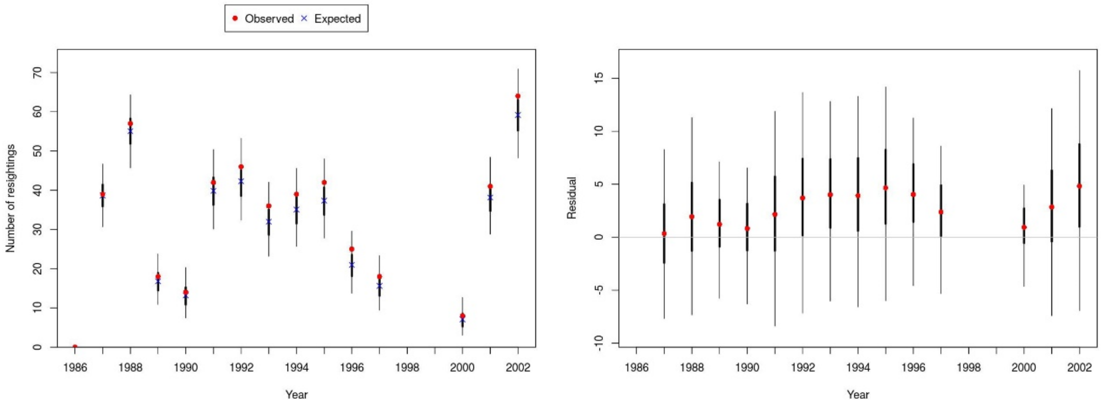
Model S2.p4: Observed and expected number of individuals resighted each year, and associated residuals.



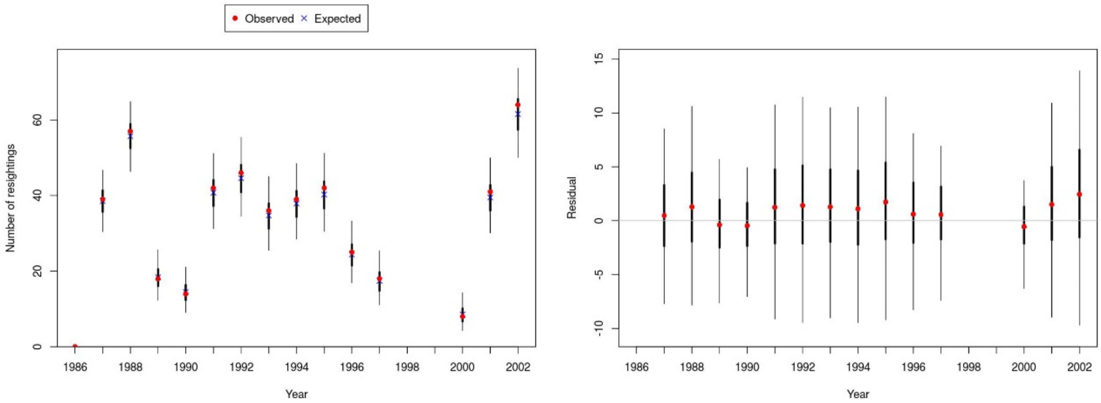
Model S3.p1: Observed and expected number of individuals resighted each year, and associated residuals.



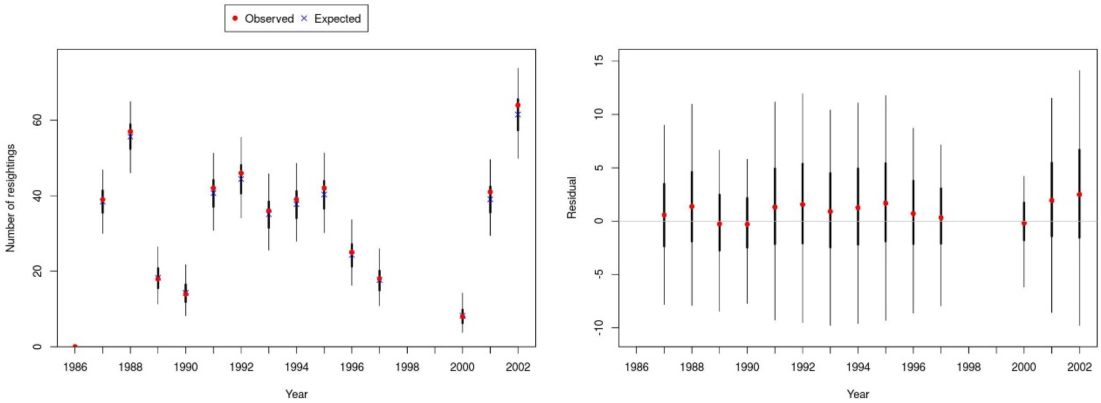
Model S3.p2: Observed and expected number of individuals resighted each year, and associated residuals.



Model S3.p3: Observed and expected number of individuals resighted each year, and associated residuals.



Model S3.p4: observed and expected number of individuals resighted each year, and associated residuals



APPENDIX E: NUMERICAL SUMMARIES OF POSTIEROR DISTRIBUTIONS FROM JAGS

Table E.2: Numerical summaries of posterior distributions for models 1a and 2b, also fitted in SEABIRD. The posterior mean and central 95% credible interval (CI) are given.

		Model 1a
Parameter	Post. mean	95% CI
p_{87}	0.563	(0.443, 0.679)
p_{88}	0.670	(0.562, 0.771)
p_{89}	0.181	(0.113, 0.262)
p_{90}	0.151	(0.087, 0.230)
p_{91}	0.461	(0.355, 0.570)
p_{92}	0.486	(0.381, 0.593)
p_{93}	0.350	(0.259, 0.446)
p_{94}	0.392	(0.297, 0.495)
p_{95}	0.450	(0.347, 0.558)
p_{96}	0.275	(0.188, 0.373)
p_{97}	0.215	(0.135, 0.312)
p_{00}	0.163	(0.077, 0.274)
p_{01}	0.554	(0.427, 0.681)
p_{02}	0.615	(0.500, 0.731)
S_{pre}	0.903	(0.860, 0.942)
S_{post}	0.860	(0.833, 0.886)
ΔS	-0.043	(-0.096, 0.011)

		Model 2b
Parameter	Post. mean	95% CI
p_{87-88}	0.621	(0.538, 0.701)
p_{89-90}	0.161	(0.113, 0.217)
p_{91-95}	0.423	(0.373, 0.474)
p_{96-97}	0.244	(0.181, 0.315)
p_{00}	0.164	(0.078, 0.277)
p_{01-02}	0.590	(0.497, 0.685)
S_{pre}	0.907	(0.864, 0.946)
S_{post}	0.859	(0.833, 0.885)
ΔS	-0.048	(-0.100, 0.007)

Table E.3: Numerical summaries of posterior distributions for S1 models. The posterior mean and central 95% credible interval (CI) are given.

Model S1.p1		
Parameter	Post. mean	95% CI
μ_α	1.479	(0.787, 2.216)
σ_α	0.906	(0.538, 1.495)
μ_β	5.360	(4.096, 6.781)
σ_β	0.680	(0.034, 1.977)
μ_{S1}	2.427	(1.651, 3.371)
μ_{S2}	2.180	(1.746, 2.869)
σ_S	0.424	(0.080, 1.340)
ΔS	-0.017	(-0.093, 0.081)
S_{86}	0.915	(0.844, 0.973)
S_{87}	0.932	(0.873, 0.986)
S_{88}	0.901	(0.790, 0.969)
S_{89}	0.911	(0.814, 0.978)
S_{90}	0.886	(0.786, 0.964)
S_{91}	0.877	(0.773, 0.950)
S_{92}	0.891	(0.807, 0.963)
S_{93}	0.903	(0.836, 0.976)
S_{94}	0.900	(0.827, 0.974)
S_{95}	0.892	(0.797, 0.971)
S_{96}	0.889	(0.777, 0.972)
S_{97}	0.875	(0.786, 0.937)
S_{00}	0.906	(0.835, 0.981)
S_{01}	0.906	(0.832, 0.982)

Model S1.p2		
Parameter	Post. mean	95% CI
α_{87}	1.530	(0.634, 2.535)
α_{88}	2.345	(1.080, 3.546)
α_{89}	-0.481	(-1.219, 0.277)
α_{90}	1.175	(-0.504, 3.393)
α_{91}	2.511	(0.799, 4.550)
α_{92}	2.372	(0.906, 4.069)
α_{93}	0.985	(-0.202, 2.029)
α_{94}	1.987	(0.439, 3.760)
α_{95}	2.683	(1.194, 4.931)
α_{96}	1.292	(-0.025, 2.802)
α_{97}	0.887	(-0.637, 2.509)
α_{00}	0.255	(-2.356, 2.366)
α_{01}	3.406	(1.641, 6.289)
α_{02}	2.859	(1.602, 4.586)
μ_β	5.952	(4.182, 8.151)
σ_β	2.007	(0.171, 4.792)
μ_{S1}	2.460	(1.700, 3.492)
μ_{S2}	2.251	(1.784, 2.999)
σ_S	0.430	(0.079, 1.373)
ΔS	-0.014	(-0.090, 0.079)
S_{86}	0.915	(0.843, 0.973)
S_{87}	0.932	(0.873, 0.987)
S_{88}	0.908	(0.809, 0.976)
S_{89}	0.911	(0.810, 0.980)
S_{90}	0.885	(0.771, 0.962)
S_{91}	0.878	(0.764, 0.949)
S_{92}	0.897	(0.813, 0.970)
S_{93}	0.908	(0.841, 0.978)
S_{94}	0.903	(0.827, 0.976)
S_{95}	0.899	(0.808, 0.976)
S_{96}	0.898	(0.796, 0.976)
S_{97}	0.890	(0.806, 0.958)
S_{00}	0.911	(0.838, 0.983)
S_{01}	0.911	(0.834, 0.984)

Model S1.p3					
Parameter	Post. mean	95% CI	Parameter	Post. mean	95% CI
π	0.138	(0.007, 0.724)	μ_{S1}	2.255	(1.646, 2.963)
δ	5.314	(0.117, 9.796)	μ_{S2}	1.868	(1.542, 2.306)
$p_{1,87}$	0.520	(0.371, 0.657)	σ_S	0.314	(0.075, 0.944)
$p_{1,88}$	0.631	(0.498, 0.748)	ΔS	-0.037	(-0.106, 0.046)
$p_{1,89}$	0.118	(0.019, 0.227)	S_{86}	0.899	(0.830, 0.952)
$p_{1,90}$	0.091	(0.009, 0.195)	S_{87}	0.916	(0.859, 0.971)
$p_{1,91}$	0.410	(0.271, 0.542)	S_{88}	0.895	(0.804, 0.956)
$p_{1,92}$	0.440	(0.302, 0.569)	S_{89}	0.898	(0.814, 0.960)
$p_{1,93}$	0.293	(0.162, 0.417)	S_{90}	0.861	(0.778, 0.937)
$p_{1,94}$	0.332	(0.200, 0.458)	S_{91}	0.854	(0.768, 0.918)
$p_{1,95}$	0.388	(0.249, 0.520)	S_{92}	0.859	(0.778, 0.924)
$p_{1,96}$	0.207	(0.077, 0.334)	S_{93}	0.878	(0.817, 0.955)
$p_{1,97}$	0.147	(0.031, 0.272)	S_{94}	0.874	(0.807, 0.950)
$p_{1,00}$	0.108	(0.012, 0.238)	S_{95}	0.862	(0.772, 0.938)
$p_{1,01}$	0.511	(0.355, 0.657)	S_{96}	0.863	(0.773, 0.942)
$p_{1,02}$	0.581	(0.427, 0.752)	S_{97}	0.848	(0.774, 0.900)
$p_{2,87}$	0.929	(0.554, 1.000)	S_{00}	0.868	(0.793, 0.946)
$p_{2,88}$	0.949	(0.658, 1.000)	S_{01}	0.858	(0.733, 0.942)
$p_{2,89}$	0.799	(0.171, 1.000)			
$p_{2,90}$	0.774	(0.139, 0.999)			
$p_{2,91}$	0.907	(0.455, 1.000)			
$p_{2,92}$	0.913	(0.483, 1.000)			
$p_{2,93}$	0.877	(0.346, 1.000)			
$p_{2,94}$	0.888	(0.383, 1.000)			
$p_{2,95}$	0.902	(0.434, 1.000)			
$p_{2,96}$	0.847	(0.259, 1.000)			
$p_{2,97}$	0.818	(0.197, 1.000)			
$p_{2,00}$	0.786	(0.142, 1.000)			
$p_{2,01}$	0.927	(0.543, 1.000)			
$p_{2,02}$	0.940	(0.604, 1.000)			

Model S1.p4		
Parameter	Post. mean	95% CI
p_{87}	0.564	(0.444, 0.682)
p_{88}	0.666	(0.558, 0.768)
p_{89}	0.182	(0.113, 0.264)
p_{90}	0.151	(0.087, 0.232)
p_{91}	0.461	(0.355, 0.572)
p_{92}	0.490	(0.383, 0.600)
p_{93}	0.353	(0.260, 0.453)
p_{94}	0.389	(0.292, 0.491)
p_{95}	0.442	(0.337, 0.553)
p_{96}	0.271	(0.182, 0.372)
p_{97}	0.211	(0.130, 0.310)
p_{00}	0.165	(0.077, 0.280)
p_{01}	0.553	(0.425, 0.682)
p_{02}	0.618	(0.490, 0.771)
μ_{S1}	2.261	(1.651, 2.947)
μ_{S2}	1.868	(1.544, 2.310)
σ_S	0.314	(0.075, 0.933)
ΔS	-0.037	(-0.106, 0.046)
S_{86}	0.899	(0.830, 0.951)
S_{87}	0.916	(0.859, 0.971)
S_{88}	0.896	(0.809, 0.956)
S_{89}	0.899	(0.814, 0.960)
S_{90}	0.861	(0.779, 0.938)
S_{91}	0.853	(0.767, 0.918)
S_{92}	0.859	(0.778, 0.925)
S_{93}	0.879	(0.817, 0.955)
S_{94}	0.874	(0.808, 0.948)
S_{95}	0.862	(0.773, 0.939)
S_{96}	0.863	(0.770, 0.943)
S_{97}	0.850	(0.777, 0.903)
S_{00}	0.868	(0.792, 0.944)
S_{01}	0.858	(0.733, 0.942)

Table E.4: Numerical summaries of posterior distributions for S2 models. The posterior mean and central 95% credible interval (CI) are given.

Model S2.p1

Parameter	Post. mean	95% CI
μ_α	1.489	(0.784, 2.235)
σ_α	0.903	(0.535, 1.498)
μ_β	5.389	(4.039, 6.841)
σ_β	0.682	(0.023, 1.988)
μ_S	2.267	(1.929, 2.813)
σ_S	0.402	(0.079, 1.226)
S_{86}	0.905	(0.846, 0.963)
S_{87}	0.923	(0.872, 0.983)
S_{88}	0.889	(0.795, 0.953)
S_{89}	0.899	(0.815, 0.967)
S_{90}	0.896	(0.811, 0.962)
S_{91}	0.885	(0.783, 0.947)
S_{92}	0.896	(0.813, 0.962)
S_{93}	0.908	(0.844, 0.973)
S_{94}	0.904	(0.832, 0.971)
S_{95}	0.898	(0.807, 0.970)
S_{96}	0.895	(0.788, 0.969)
S_{97}	0.881	(0.792, 0.938)
S_{00}	0.912	(0.848, 0.980)
S_{01}	0.913	(0.846, 0.981)

Model S2.p2

Parameter	Post. mean	95% CI
α_{87}	1.556	(0.643, 2.561)
α_{88}	2.341	(1.042, 3.560)
α_{89}	-0.459	(-1.212, 0.306)
α_{90}	1.225	(-0.434, 3.395)
α_{91}	2.541	(0.835, 4.591)
α_{92}	2.336	(0.874, 4.004)
α_{93}	0.982	(-0.216, 2.041)
α_{94}	2.017	(0.451, 3.824)
α_{95}	2.692	(1.202, 4.993)
α_{96}	1.278	(-0.003, 2.722)
α_{97}	0.891	(-0.627, 2.504)
α_{00}	0.220	(-2.390, 2.302)
α_{01}	3.454	(1.619, 6.631)
α_{02}	2.895	(1.623, 4.741)
μ_β	5.975	(4.181, 8.251)
σ_β	2.053	(0.139, 4.978)
μ_S	2.306	(1.962, 2.852)
σ_S	0.382	(0.078, 1.169)
S_{86}	0.906	(0.846, 0.960)
S_{87}	0.923	(0.874, 0.982)
S_{88}	0.899	(0.815, 0.962)
S_{89}	0.901	(0.820, 0.965)
S_{90}	0.895	(0.805, 0.957)
S_{91}	0.887	(0.783, 0.948)
S_{92}	0.901	(0.824, 0.963)
S_{93}	0.911	(0.850, 0.973)
S_{94}	0.906	(0.835, 0.970)
S_{95}	0.904	(0.822, 0.972)
S_{96}	0.902	(0.810, 0.969)
S_{97}	0.894	(0.813, 0.955)
S_{00}	0.914	(0.849, 0.979)
S_{01}	0.914	(0.849, 0.980)

Model S2.p3

Parameter	Post. mean	95% CI	Parameter	Post. mean	95% CI
π	0.139	(0.009, 0.566)	μ_S	1.991	(1.724, 2.377)
δ	5.274	(0.109, 9.795)	σ_S	0.328	(0.077, 0.918)
$p_{1,87}$	0.522	(0.374, 0.657)	S_{86}	0.881	(0.822, 0.938)
$p_{1,88}$	0.636	(0.505, 0.752)	S_{87}	0.901	(0.849, 0.967)
$p_{1,89}$	0.120	(0.018, 0.231)	S_{88}	0.874	(0.795, 0.939)
$p_{1,90}$	0.094	(0.010, 0.201)	S_{89}	0.877	(0.800, 0.945)
$p_{1,91}$	0.415	(0.276, 0.546)	S_{90}	0.877	(0.803, 0.944)
$p_{1,92}$	0.440	(0.303, 0.569)	S_{91}	0.863	(0.774, 0.924)
$p_{1,93}$	0.290	(0.160, 0.417)	S_{92}	0.868	(0.783, 0.929)
$p_{1,94}$	0.327	(0.195, 0.454)	S_{93}	0.887	(0.826, 0.957)
$p_{1,95}$	0.382	(0.246, 0.513)	S_{94}	0.883	(0.816, 0.952)
$p_{1,96}$	0.200	(0.072, 0.326)	S_{95}	0.871	(0.777, 0.943)
$p_{1,97}$	0.141	(0.028, 0.263)	S_{96}	0.872	(0.778, 0.946)
$p_{1,00}$	0.102	(0.010, 0.232)	S_{97}	0.853	(0.773, 0.905)
$p_{1,01}$	0.498	(0.344, 0.645)	S_{00}	0.879	(0.803, 0.951)
$p_{1,02}$	0.560	(0.413, 0.721)	S_{01}	0.871	(0.758, 0.948)
$p_{2,87}$	0.928	(0.561, 1.000)			
$p_{2,88}$	0.949	(0.669, 1.000)			
$p_{2,89}$	0.796	(0.176, 1.000)			
$p_{2,90}$	0.773	(0.147, 0.999)			
$p_{2,91}$	0.906	(0.465, 1.000)			
$p_{2,92}$	0.911	(0.489, 1.000)			
$p_{2,93}$	0.873	(0.348, 1.000)			
$p_{2,94}$	0.884	(0.383, 1.000)			
$p_{2,95}$	0.898	(0.433, 1.000)			
$p_{2,96}$	0.841	(0.257, 1.000)			
$p_{2,97}$	0.810	(0.196, 1.000)			
$p_{2,00}$	0.776	(0.139, 1.000)			
$p_{2,01}$	0.923	(0.533, 1.000)			
$p_{2,02}$	0.935	(0.592, 1.000)			

Model S2.p4

Parameter	Post. mean	95% CI
p_{87}	0.567	(0.446, 0.686)
p_{88}	0.672	(0.563, 0.773)
p_{89}	0.187	(0.116, 0.270)
p_{90}	0.158	(0.091, 0.240)
p_{91}	0.469	(0.361, 0.579)
p_{92}	0.492	(0.385, 0.602)
p_{93}	0.353	(0.260, 0.452)
p_{94}	0.388	(0.291, 0.490)
p_{95}	0.439	(0.334, 0.549)
p_{96}	0.267	(0.180, 0.367)
p_{97}	0.207	(0.127, 0.303)
p_{00}	0.163	(0.076, 0.276)
p_{01}	0.544	(0.417, 0.673)
p_{02}	0.602	(0.482, 0.747)
μ_S	1.990	(1.722, 2.376)
σ_S	0.327	(0.077, 0.928)
S_{86}	0.881	(0.821, 0.937)
S_{87}	0.901	(0.849, 0.967)
S_{88}	0.875	(0.799, 0.940)
S_{89}	0.877	(0.802, 0.945)
S_{90}	0.877	(0.803, 0.943)
S_{91}	0.863	(0.773, 0.924)
S_{92}	0.868	(0.784, 0.929)
S_{93}	0.887	(0.827, 0.957)
S_{94}	0.883	(0.818, 0.953)
S_{95}	0.872	(0.782, 0.947)
S_{96}	0.873	(0.780, 0.948)
S_{97}	0.853	(0.771, 0.904)
S_{00}	0.878	(0.804, 0.950)
S_{01}	0.871	(0.751, 0.950)

Table E.5: Numerical summaries of posterior distributions for S3 models. The posterior mean and central 95% credible interval (CI) are given.

Model S3.p1

Parameter	Post. mean	95% CI
μ_α	1.418	(0.724, 2.156)
σ_α	0.871	(0.508, 1.450)
μ_β	5.148	(3.834, 6.616)
σ_β	0.645	(0.033, 1.840)
S_{86}	0.903	(0.796, 0.987)
S_{87}	0.965	(0.889, 0.999)
S_{88}	0.856	(0.707, 0.986)
S_{89}	0.897	(0.734, 0.995)
S_{90}	0.887	(0.732, 0.993)
S_{91}	0.843	(0.700, 0.975)
S_{92}	0.880	(0.735, 0.991)
S_{93}	0.929	(0.802, 0.997)
S_{94}	0.914	(0.765, 0.996)
S_{95}	0.871	(0.673, 0.994)
S_{96}	0.843	(0.610, 0.993)
S_{97}	0.859	(0.747, 0.971)
S_{00}	0.933	(0.791, 0.998)
S_{01}	0.924	(0.748, 0.998)

Model S3.p2

Parameter	Post. mean	95% CI
α_{87}	1.516	(0.645, 2.495)
α_{88}	2.270	(1.046, 3.367)
α_{89}	-0.459	(-1.215, 0.314)
α_{90}	1.018	(-0.509, 3.120)
α_{91}	2.407	(0.805, 4.369)
α_{92}	2.308	(0.963, 3.974)
α_{93}	0.974	(-0.204, 1.971)
α_{94}	1.815	(0.421, 3.454)
α_{95}	2.405	(1.066, 4.565)
α_{96}	1.189	(-0.021, 2.615)
α_{97}	0.841	(-0.563, 2.381)
α_{00}	0.280	(-2.169, 2.161)
α_{01}	3.029	(1.521, 5.715)
α_{02}	2.675	(1.510, 4.521)
μ_β	5.615	(3.997, 7.668)
σ_β	1.680	(0.077, 4.384)
S_{86}	0.897	(0.791, 0.985)
S_{87}	0.963	(0.885, 0.999)
S_{88}	0.881	(0.729, 0.993)
S_{89}	0.896	(0.733, 0.995)
S_{90}	0.871	(0.712, 0.990)
S_{91}	0.837	(0.691, 0.973)
S_{92}	0.893	(0.745, 0.994)
S_{93}	0.929	(0.800, 0.997)
S_{94}	0.908	(0.762, 0.996)
S_{95}	0.884	(0.690, 0.995)
S_{96}	0.855	(0.623, 0.994)
S_{97}	0.873	(0.752, 0.986)
S_{00}	0.928	(0.772, 0.998)
S_{01}	0.913	(0.704, 0.997)

Model S3.p3

Parameter	Post. mean	95% CI	Parameter	Post. mean	95% CI
π	0.136	(0.008, 0.621)	S_{86}	0.872	(0.768, 0.964)
δ	5.382	(0.142, 9.787)	S_{87}	0.957	(0.869, 0.999)
$p_{1,87}$	0.528	(0.375, 0.667)	S_{88}	0.856	(0.702, 0.989)
$p_{1,88}$	0.615	(0.480, 0.735)	S_{89}	0.879	(0.708, 0.994)
$p_{1,89}$	0.117	(0.018, 0.231)	S_{90}	0.884	(0.726, 0.993)
$p_{1,90}$	0.092	(0.009, 0.199)	S_{91}	0.827	(0.688, 0.964)
$p_{1,91}$	0.404	(0.260, 0.541)	S_{92}	0.833	(0.693, 0.970)
$p_{1,92}$	0.444	(0.298, 0.582)	S_{93}	0.929	(0.797, 0.997)
$p_{1,93}$	0.302	(0.166, 0.433)	S_{94}	0.911	(0.764, 0.996)
$p_{1,94}$	0.322	(0.187, 0.451)	S_{95}	0.844	(0.644, 0.991)
$p_{1,95}$	0.363	(0.223, 0.499)	S_{96}	0.848	(0.612, 0.994)
$p_{1,96}$	0.196	(0.065, 0.334)	S_{97}	0.828	(0.727, 0.933)
$p_{1,97}$	0.142	(0.026, 0.279)	S_{00}	0.887	(0.717, 0.994)
$p_{1,00}$	0.109	(0.012, 0.245)	S_{01}	0.733	(0.497, 0.984)
$p_{1,01}$	0.506	(0.346, 0.659)			
$p_{1,02}$	0.709	(0.435, 0.983)			
$p_{2,87}$	0.938	(0.574, 1.000)			
$p_{2,88}$	0.952	(0.657, 1.000)			
$p_{2,89}$	0.813	(0.178, 1.000)			
$p_{2,90}$	0.789	(0.147, 0.999)			
$p_{2,91}$	0.915	(0.461, 1.000)			
$p_{2,92}$	0.923	(0.499, 1.000)			
$p_{2,93}$	0.891	(0.368, 1.000)			
$p_{2,94}$	0.896	(0.388, 1.000)			
$p_{2,95}$	0.906	(0.423, 1.000)			
$p_{2,96}$	0.856	(0.260, 1.000)			
$p_{2,97}$	0.829	(0.200, 1.000)			
$p_{2,00}$	0.802	(0.152, 1.000)			
$p_{2,01}$	0.934	(0.550, 1.000)			
$p_{2,02}$	0.964	(0.661, 1.000)			

Model S3.p4

Parameter	Post. mean	95% CI
p_{87}	0.574	(0.450, 0.694)
p_{88}	0.653	(0.544, 0.756)
p_{89}	0.185	(0.113, 0.273)
p_{90}	0.156	(0.089, 0.239)
p_{91}	0.459	(0.349, 0.573)
p_{92}	0.497	(0.383, 0.613)
p_{93}	0.366	(0.267, 0.474)
p_{94}	0.385	(0.287, 0.489)
p_{95}	0.424	(0.318, 0.538)
p_{96}	0.265	(0.173, 0.377)
p_{97}	0.210	(0.124, 0.324)
p_{00}	0.171	(0.080, 0.291)
p_{01}	0.552	(0.422, 0.685)
p_{02}	0.731	(0.495, 0.983)
S_{86}	0.871	(0.767, 0.965)
S_{87}	0.957	(0.870, 0.999)
S_{88}	0.861	(0.706, 0.989)
S_{89}	0.879	(0.707, 0.994)
S_{90}	0.883	(0.721, 0.993)
S_{91}	0.826	(0.686, 0.963)
S_{92}	0.832	(0.694, 0.969)
S_{93}	0.928	(0.798, 0.997)
S_{94}	0.908	(0.760, 0.996)
S_{95}	0.849	(0.652, 0.992)
S_{96}	0.849	(0.616, 0.993)
S_{97}	0.829	(0.727, 0.936)
S_{00}	0.886	(0.716, 0.994)
S_{01}	0.739	(0.499, 0.984)

APPENDIX F: MCMC OUTPUTS FROM SEABIRD

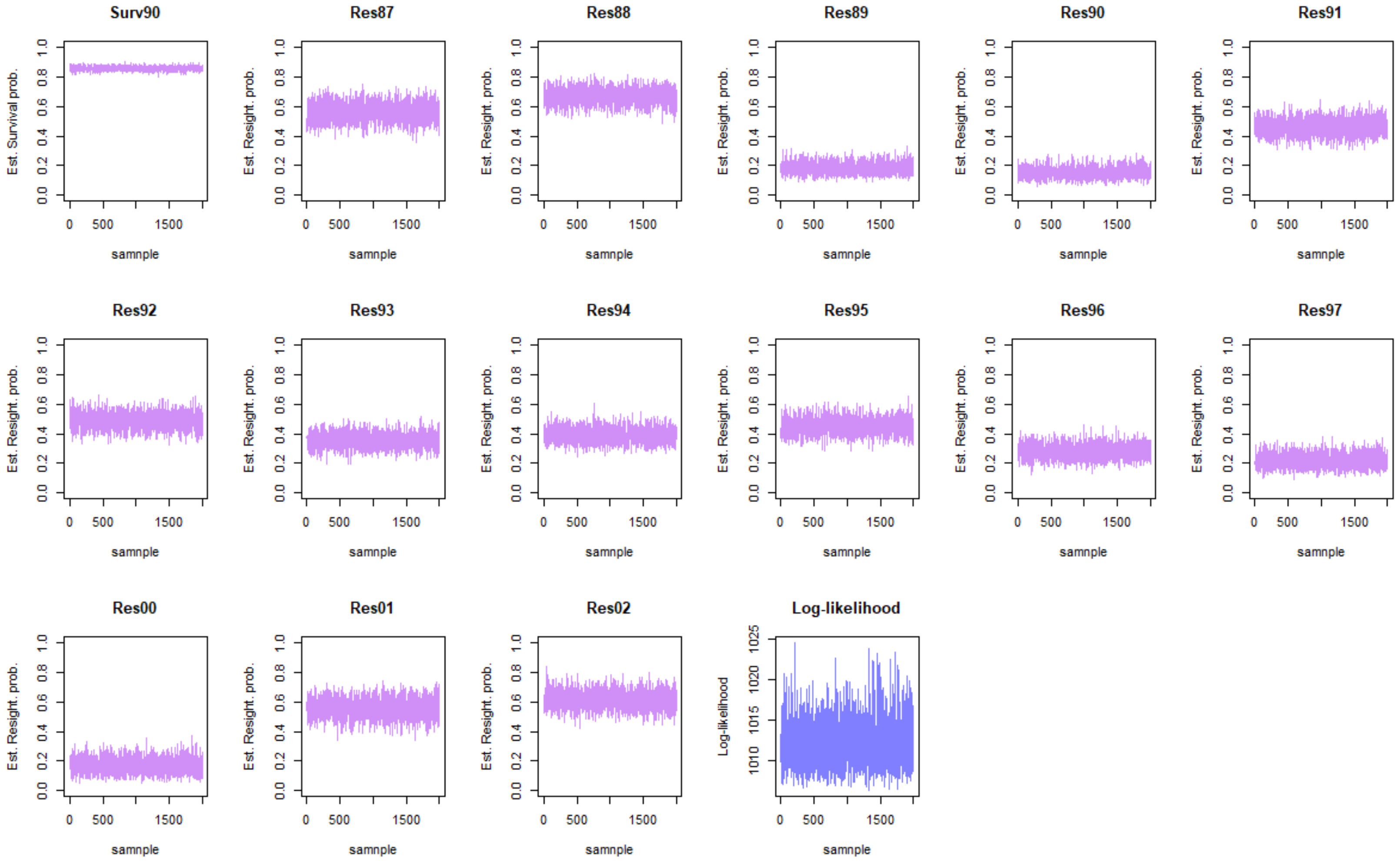


Figure F.3: MCMC traces for all estimated parameters of the reference model run (model run 1a). “Surv86” and “Surv90” are the annual survival probabilities in 1986–89 and 1990–01, respectively. Parameters with prefix “Res” are annual resighting probabilities for a respective year, e.g., “Res87” applies to the 1986/87 field season.

Table F.6: MCMC run estimates of all parameters for model runs except 1b and 3c. $Surv_{change}$ is a derived quantity; 95% credible intervals in parentheses.

Parameter	Reference (1a)
Res_{87}	0.566 (0.447 – 0.681)
Res_{88}	0.670 (0.566 – 0.771)
Res_{89}	0.179 (0.116 – 0.266)
Res_{90}	0.148 (0.087 – 0.228)
Res_{91}	0.461 (0.353 – 0.571)
Res_{92}	0.487 (0.383 – 0.591)
Res_{93}	0.348 (0.259 – 0.451)
Res_{94}	0.389 (0.299 – 0.486)
Res_{95}	0.450 (0.348 – 0.561)
Res_{96}	0.275 (0.188 – 0.377)
Res_{97}	0.214 (0.134 – 0.311)
Res_{00}	0.156 (0.078 – 0.273)
Res_{01}	0.555 (0.433 – 0.680)
Res_{02}	0.617 (0.499 – 0.734)
$Surv_{pre}$	0.903 (0.859 – 0.941)
$Surv_{post}$	0.860 (0.832 – 0.885)
$\boldsymbol{Surv_{change}}$	**-0.043 (-0.098 – 0.011)**

Parameter	Start_1985 (4)
Res_{86}	0.588 (0.309 – 0.847)
Res_{87}	0.536 (0.427 – 0.649)
Res_{88}	0.657 (0.544 – 0.756)
Res_{89}	0.175 (0.108 – 0.252)
Res_{90}	0.160 (0.099 – 0.246)
Res_{91}	0.460 (0.360 – 0.567)
Res_{92}	0.483 (0.378 – 0.592)
Res_{93}	0.346 (0.258 – 0.444)
Res_{94}	0.390 (0.293 – 0.498)
Res_{95}	0.448 (0.341 – 0.560)
Res_{96}	0.272 (0.193 – 0.372)
Res_{97}	0.215 (0.133 – 0.315)
Res_{00}	0.157 (0.076 – 0.280)
Res_{01}	0.554 (0.434 – 0.679)
Res_{02}	0.614 (0.499 – 0.732)
$Surv_{pre}$	0.908 (0.868 – 0.945)
$Surv_{post}$	0.860 (0.833 – 0.886)
$\boldsymbol{Surv_{change}}$	**-0.049 (-0.099 – 0.005)**

Parameter	Res_constant (2a)
Res	0.394 (0.360 – 0.425)
$Surv_{pre}$	0.885 (0.844 – 0.923)
$Surv_{post}$	0.874 (0.849 – 0.895)
$\boldsymbol{Surv_{change}}$	**-0.012 (-0.060 – 0.038)**

Parameter	Res_block (2b)
Res_{87-88}	0.621 (0.540 – 0.702)
Res_{89-90}	0.161 (0.113 – 0.216)
Res_{91-95}	0.423 (0.376 – 0.474)
Res_{96-97}	0.242 (0.179 – 0.314)
Res_{00}	0.158 (0.078 – 0.276)
Res_{01-02}	0.592 (0.489 – 0.686)
$Surv_{pre}$	0.908 (0.867 – 0.948)
$Surv_{post}$	0.859 (0.832 – 0.884)
$\boldsymbol{Surv_{change}}$	-0.049 (-0.102 – 0.004)

Parameter	Surv_constant (3a)
Res_{87}	0.567 (0.451 – 0.686)
Res_{88}	0.681 (0.576 – 0.776)
Res_{89}	0.185 (0.116 – 0.272)
Res_{90}	0.157 (0.093 – 0.240)
Res_{91}	0.474 (0.371 – 0.582)
Res_{92}	0.492 (0.392 – 0.606)
Res_{93}	0.346 (0.263 – 0.444)
Res_{94}	0.391 (0.297 – 0.496)
Res_{95}	0.448 (0.347 – 0.555)
Res_{96}	0.268 (0.181 – 0.365)
Res_{97}	0.208 (0.128 – 0.307)
Res_{00}	0.153 (0.075 – 0.270)
Res_{01}	0.537 (0.416 – 0.665)
Res_{02}	0.592 (0.479 – 0.712)
$Surv$	0.874 (0.854 – 0.893)

Parameter	Surv_annual (3b)
Res_{87}	0.575 (0.443 – 0.692)
Res_{88}	0.653 (0.536 – 0.757)
Res_{89}	0.184 (0.114 – 0.273)
Res_{90}	0.154 (0.088 – 0.239)
Res_{91}	0.460 (0.346 – 0.579)
Res_{92}	0.497 (0.379 – 0.612)
Res_{93}	0.363 (0.270 – 0.473)
Res_{94}	0.382 (0.285 – 0.489)
Res_{95}	0.420 (0.316 – 0.532)
Res_{96}	0.259 (0.172 – 0.382)
Res_{97}	0.208 (0.123 – 0.327)
Res_{00}	0.166 (0.081 – 0.290)
Res_{01}	0.553 (0.420 – 0.683)
Res_{02}	0.724 (0.500 – 0.984)
$Surv_{86}$	0.875 (0.762 – 0.961)
$Surv_{87}$	0.966 (0.875 – 0.998)
$Surv_{88}$	0.863 (0.713 – 0.989)
$Surv_{89}$	0.889 (0.712 – 0.993)
$Surv_{90}$	0.890 (0.718 – 0.992)
$Surv_{91}$	0.827 (0.689 – 0.959)
$Surv_{92}$	0.835 (0.694 – 0.965)
$Surv_{93}$	0.942 (0.798 – 0.997)
$Surv_{94}$	0.919 (0.765 – 0.996)
$Surv_{95}$	0.856 (0.646 – 0.993)
$Surv_{96}$	0.865 (0.639 – 0.993)
$Surv_{97}$	0.828 (0.728 – 0.936)
$Surv_{00}$	0.897 (0.715 – 0.993)
$Surv_{01}$	0.722 (0.498 – 0.983)

Table F.7: MCMC run estimates of all parameters for model runs 1b (retrospective). Estimates labelled with model period. $Surv_{change}$ is a derived quantity; 95% credible intervals in parentheses.

Parameter	1986–1991	Parameter	1986–1992	Parameter	1986–1993	Parameter	1986–1994	Parameter	1986–1995
Res_{87}	0.589 (0.465 – 0.714)	Res_{87}	0.569 (0.446 – 0.684)	Res_{87}	0.575 (0.445 – 0.695)	Res_{87}	0.569 (0.448 – 0.682)	Res_{87}	0.568 (0.442 – 0.684)
Res_{88}	0.710 (0.592 – 0.816)	Res_{88}	0.678 (0.566 – 0.784)	Res_{88}	0.686 (0.572 – 0.787)	Res_{88}	0.679 (0.568 – 0.783)	Res_{88}	0.677 (0.571 – 0.782)
Res_{89}	0.194 (0.123 – 0.288)	Res_{89}	0.181 (0.114 – 0.266)	Res_{89}	0.188 (0.117 – 0.276)	Res_{89}	0.180 (0.112 – 0.260)	Res_{89}	0.181 (0.114 – 0.263)
Res_{90}	0.164 (0.093 – 0.257)	Res_{90}	0.150 (0.087 – 0.236)	Res_{90}	0.154 (0.091 – 0.242)	Res_{90}	0.150 (0.085 – 0.231)	Res_{90}	0.149 (0.084 – 0.229)
Res_{91}	0.650 (0.391 – 0.982)	Res_{91}	0.559 (0.411 – 0.706)	Res_{91}	0.516 (0.395 – 0.638)	Res_{91}	0.502 (0.386 – 0.627)	Res_{91}	0.488 (0.374 – 0.599)
$Surv_{pre}$	0.875 (0.812 – 0.934)	Res_{92}	0.683 (0.436 – 0.945)	Res_{92}	0.558 (0.422 – 0.707)	Res_{92}	0.552 (0.429 – 0.672)	Res_{92}	0.533 (0.417 – 0.652)
$Surv_{post}$	0.672 (0.396 – 0.980)	$Surv_{pre}$	0.900 (0.844 – 0.951)	Res_{93}	0.418 (0.276 – 0.593)	Res_{93}	0.419 (0.307 – 0.547)	Res_{93}	0.410 (0.305 – 0.522)
$Surv_{change}$	**-0.193 (-0.503 – 0.117)**	$Surv_{post}$	0.708 (0.555 – 0.925)	$Surv_{pre}$	0.890 (0.836 – 0.941)	Res_{94}	0.514 (0.355 – 0.708)	Res_{94}	0.505 (0.367 – 0.637)
		$Surv_{change}$	**-0.192 (-0.372 – 0.053)**	$Surv_{post}$	0.798 (0.689 – 0.921)	$Surv_{pre}$	0.899 (0.847 – 0.947)	Res_{95}	0.633 (0.456 – 0.817)
				$Surv_{change}$	**-0.089 (-0.238 – 0.066)**	$Surv_{post}$	0.795 (0.709 – 0.878)	$Surv_{pre}$	0.902 (0.853 – 0.945)
						$Surv_{change}$	**-0.103 (-0.217 – 0.012)**	$Surv_{post}$	0.796 (0.738 – 0.856)
								$Surv_{change}$	**-0.106 (-0.191 – -0.013)**

Parameter	1986–1996	Parameter	1986–1997	Parameter	1986–2000	Parameter	1986–2001	Parameter	1986–2002
Res_{87}	0.568 (0.437 – 0.686)	Res_{87}	0.567 (0.446 – 0.688)	Res_{87}	0.570 (0.445 – 0.680)	Res_{87}	0.571 (0.442 – 0.686)	Res_{87}	0.561 (0.439 – 0.678)
Res_{88}	0.681 (0.579 – 0.782)	Res_{88}	0.681 (0.570 – 0.778)	Res_{88}	0.680 (0.576 – 0.784)	Res_{88}	0.682 (0.573 – 0.787)	Res_{88}	0.671 (0.563 – 0.770)
Res_{89}	0.182 (0.116 – 0.266)	Res_{89}	0.180 (0.115 – 0.265)	Res_{89}	0.182 (0.113 – 0.271)	Res_{89}	0.181 (0.118 – 0.266)	Res_{89}	0.179 (0.113 – 0.260)
Res_{90}	0.149 (0.088 – 0.232)	Res_{90}	0.151 (0.088 – 0.234)	Res_{90}	0.151 (0.089 – 0.232)	Res_{90}	0.149 (0.087 – 0.229)	Res_{90}	0.147 (0.085 – 0.226)
Res_{91}	0.478 (0.372 – 0.590)	Res_{91}	0.477 (0.368 – 0.593)	Res_{91}	0.481 (0.368 – 0.593)	Res_{91}	0.476 (0.371 – 0.590)	Res_{91}	0.462 (0.357 – 0.570)
Res_{92}	0.514 (0.411 – 0.622)	Res_{92}	0.514 (0.407 – 0.627)	Res_{92}	0.516 (0.406 – 0.630)	Res_{92}	0.510 (0.406 – 0.626)	Res_{92}	0.486 (0.382 – 0.590)
Res_{93}	0.385 (0.285 – 0.488)	Res_{93}	0.386 (0.284 – 0.491)	Res_{93}	0.377 (0.279 – 0.488)	Res_{93}	0.374 (0.280 – 0.483)	Res_{93}	0.349 (0.262 – 0.445)
Res_{94}	0.456 (0.349 – 0.573)	Res_{94}	0.452 (0.343 – 0.569)	Res_{94}	0.438 (0.340 – 0.549)	Res_{94}	0.440 (0.337 – 0.549)	Res_{94}	0.391 (0.301 – 0.490)
Res_{95}	0.557 (0.415 – 0.703)	Res_{95}	0.551 (0.417 – 0.685)	Res_{95}	0.526 (0.396 – 0.663)	Res_{95}	0.520 (0.400 – 0.634)	Res_{95}	0.450 (0.348 – 0.559)
Res_{96}	0.343 (0.230 – 0.489)	Res_{96}	0.346 (0.235 – 0.486)	Res_{96}	0.324 (0.220 – 0.455)	Res_{96}	0.328 (0.225 – 0.445)	Res_{96}	0.275 (0.189 – 0.375)
$Surv_{pre}$	0.901 (0.856 – 0.945)	Res_{97}	0.277 (0.169 – 0.419)	Res_{97}	0.256 (0.160 – 0.379)	Res_{97}	0.261 (0.164 – 0.376)	Res_{97}	0.213 (0.135 – 0.308)
$Surv_{post}$	0.821 (0.770 – 0.871)	$Surv_{pre}$	0.902 (0.854 – 0.942)	Res_{00}	0.211 (0.090 – 0.399)	Res_{00}	0.235 (0.112 – 0.411)	Res_{00}	0.157 (0.075 – 0.273)
$Surv_{change}$	**-0.080(-0.160 – -0.001)**	$Surv_{post}$	0.821 (0.772 – 0.866)	$Surv_{pre}$	0.899 (0.852 – 0.938)	Res_{01}	0.726 (0.549 – 0.908)	Res_{01}	0.555 (0.426 – 0.683)
		$Surv_{change}$	**-0.081 (-0.158 – -0.008)**	$Surv_{post}$	0.831 (0.785 – 0.876)	$Surv_{pre}$	0.900 (0.854 – 0.941)	Res_{02}	0.615 (0.498 – 0.733)
				$Surv_{change}$	**-0.067 (-0.138 – 0.003)**	$Surv_{post}$	0.824 (0.790 – 0.857)	$Surv_{pre}$	0.903 (0.859 – 0.944)
						$Surv_{change}$	**-0.077 (-0.138 – -0.010)**	$Surv_{post}$	0.860 (0.833 – 0.888)
								$Surv_{change}$	**-0.043 (-0.098 – 0.014)**

Table F.8: MCMC run estimates of all parameters for model run 3c (Surv_breakpoint), trialling alternative annual survival year blocks. Estimates labelled with annual survival year blocks. *Surv*$_{change}$ is a derived quantity; 95% credible intervals in parentheses.

	Annual survival year blocks						
Parameter	1986, 1987–2001	1986–1987, 1988–2001	1986–1988, 1989–2001	1986–1989, 1990–2001	1986–1990, 1991–2001	1986–1991, 1992–2001	1986–1992, 1993–2001
Res_{87}	0.556 (0.435 – 0.673)	0.554 (0.432 – 0.674)	0.561 (0.439 – 0.672)	0.564 (0.447 – 0.676)	0.565 (0.452 – 0.687)	0.566 (0.452 – 0.685)	0.566 (0.444 – 0.680)
Res_{88}	0.674 (0.568 – 0.772)	0.656 (0.542 – 0.756)	0.665 (0.557 – 0.768)	0.673 (0.565 – 0.772)	0.676 (0.567 – 0.777)	0.679 (0.567 – 0.776)	0.678 (0.564 – 0.774)
Res_{89}	0.185 (0.115 – 0.269)	0.182 (0.114 – 0.267)	0.173 (0.111 – 0.257)	0.181 (0.115 – 0.261)	0.183 (0.118 – 0.266)	0.185 (0.116 – 0.266)	0.184 (0.120 – 0.265)
Res_{90}	0.156 (0.091 – 0.240)	0.155 (0.091 – 0.237)	0.151 (0.090 – 0.234)	0.149 (0.087 – 0.230)	0.153 (0.092 – 0.233)	0.156 (0.089 – 0.237)	0.155 (0.095 – 0.236)
Res_{91}	0.474 (0.373 – 0.587)	0.470 (0.371 – 0.582)	0.466 (0.360 – 0.575)	0.463 (0.353 – 0.572)	0.455 (0.354 – 0.573)	0.464 (0.359 – 0.572)	0.470 (0.364 – 0.579)
Res_{92}	0.493 (0.384 – 0.599)	0.491 (0.383 – 0.599)	0.489 (0.386 – 0.598)	0.488 (0.389 – 0.592)	0.482 (0.380 – 0.593)	0.477 (0.376 – 0.583)	0.483 (0.382 – 0.592)
Res_{93}	0.348 (0.258 – 0.449)	0.350 (0.258 – 0.447)	0.350 (0.258 – 0.446)	0.350 (0.259 – 0.453)	0.348 (0.259 – 0.447)	0.346 (0.256 – 0.443)	0.338 (0.247 – 0.439)
Res_{94}	0.389 (0.297 – 0.493)	0.393 (0.301 – 0.491)	0.393 (0.301 – 0.494)	0.390 (0.295 – 0.496)	0.390 (0.295 – 0.491)	0.390 (0.296 – 0.492)	0.389 (0.292 – 0.491)
Res_{95}	0.447 (0.346 – 0.558)	0.450 (0.346 – 0.562)	0.449 (0.342 – 0.560)	0.450 (0.338 – 0.559)	0.451 (0.345 – 0.558)	0.448 (0.345 – 0.561)	0.443 (0.336 – 0.552)
Res_{96}	0.271 (0.180 – 0.368)	0.273 (0.188 – 0.378)	0.274 (0.190 – 0.378)	0.273 (0.186 – 0.378)	0.272 (0.188 – 0.375)	0.273 (0.187 – 0.380)	0.271 (0.188 – 0.369)
Res_{97}	0.207 (0.133 – 0.309)	0.211 (0.134 – 0.308)	0.212 (0.136 – 0.311)	0.213 (0.138 – 0.305)	0.213 (0.138 – 0.309)	0.212 (0.136 – 0.305)	0.209 (0.131 – 0.307)
Res_{00}	0.155 (0.070 – 0.268)	0.156 (0.074 – 0.272)	0.157 (0.076 – 0.273)	0.156 (0.077 – 0.271)	0.158 (0.077 – 0.275)	0.156 (0.076 – 0.276)	0.156 (0.076 – 0.274)
Res_{01}	0.539 (0.419 – 0.671)	0.550 (0.422 – 0.670)	0.555 (0.429 – 0.680)	0.555 (0.433 – 0.675)	0.553 (0.432 – 0.680)	0.552 (0.432 – 0.675)	0.552 (0.421 – 0.677)
Res_{02}	0.598 (0.489 – 0.713)	0.609 (0.496 – 0.723)	0.615 (0.502 – 0.731)	0.616 (0.498 – 0.733)	0.616 (0.496 – 0.737)	0.615 (0.503 – 0.733)	0.615 (0.502 – 0.733)
$Surv_{pre}$	0.904 (0.799 – 0.986)	0.925 (0.860 – 0.977)	0.915 (0.860 – 0.959)	0.903 (0.861 – 0.940)	0.894 (0.859 – 0.925)	0.887 (0.853 – 0.916)	0.883 (0.854 – 0.911)
$Surv_{post}$	0.871 (0.850 – 0.891)	0.865 (0.841 – 0.886)	0.862 (0.835 – 0.884)	0.860 (0.834 – 0.885)	0.860 (0.832 – 0.885)	0.861 (0.830 – 0.889)	0.861 (0.826 – 0.893)
$Surv_{change}$	**-0.032 (-0.122 – 0.077)**	**-0.060 (-0.116 – 0.012)**	**-0.053 (-0.112 – 0.012)**	**-0.042 (-0.092 – 0.011)**	**-0.033 (-0.080 – 0.011)**	**-0.025 (-0.072 – 0.022)**	**-0.023 (-0.070 – 0.024)**

	Annual survival year blocks					
Parameter	1986–1993, 1994–2001	1986–1994, 1995–2001	1986–1995, 1996–2001	1986–1996, 1997–2001	1986–1997, 1998–2001	1986–1998, 2001
Res_{87}	0.565 (0.450 – 0.680)	0.567 (0.438 – 0.683)	0.570 (0.447 – 0.680)	0.567 (0.449 – 0.683)	0.565 (0.443 – 0.683)	0.567 (0.451 – 0.682)
Res_{88}	0.680 (0.572 – 0.777)	0.678 (0.573 – 0.774)	0.678 (0.572 – 0.776)	0.678 (0.575 – 0.775)	0.680 (0.573 – 0.777)	0.681 (0.580 – 0.781)
Res_{89}	0.184 (0.119 – 0.270)	0.184 (0.118 – 0.269)	0.185 (0.120 – 0.270)	0.186 (0.118 – 0.269)	0.184 (0.116 – 0.266)	0.186 (0.117 – 0.266)
Res_{90}	0.157 (0.092 – 0.241)	0.156 (0.092 – 0.234)	0.156 (0.089 – 0.239)	0.154 (0.091 – 0.238)	0.156 (0.093 – 0.236)	0.157 (0.097 – 0.242)
Res_{91}	0.471 (0.364 – 0.576)	0.470 (0.360 – 0.576)	0.471 (0.366 – 0.577)	0.470 (0.361 – 0.573)	0.470 (0.367 – 0.582)	0.473 (0.369 – 0.577)
Res_{92}	0.482 (0.372 – 0.594)	0.486 (0.384 – 0.592)	0.490 (0.382 – 0.598)	0.483 (0.379 – 0.589)	0.487 (0.386 – 0.592)	0.493 (0.385 – 0.596)
Res_{93}	0.342 (0.253 – 0.439)	0.342 (0.246 – 0.439)	0.345 (0.256 – 0.446)	0.343 (0.256 – 0.439)	0.346 (0.258 – 0.446)	0.350 (0.257 – 0.446)
Res_{94}	0.378 (0.285 – 0.479)	0.379 (0.289 – 0.483)	0.382 (0.286 – 0.480)	0.379 (0.287 – 0.481)	0.379 (0.288 – 0.483)	0.387 (0.294 – 0.491)
Res_{95}	0.440 (0.339 – 0.547)	0.430 (0.328 – 0.539)	0.431 (0.326 – 0.534)	0.433 (0.334 – 0.544)	0.434 (0.332 – 0.548)	0.444 (0.343 – 0.558)
Res_{96}	0.270 (0.185 – 0.370)	0.268 (0.183 – 0.366)	0.257 (0.177 – 0.354)	0.257 (0.175 – 0.356)	0.259 (0.178 – 0.352)	0.268 (0.187 – 0.368)
Res_{97}	0.211 (0.133 – 0.309)	0.209 (0.132 – 0.309)	0.205 (0.129 – 0.299)	0.196 (0.121 – 0.288)	0.197 (0.122 – 0.292)	0.209 (0.133 – 0.305)
Res_{00}	0.156 (0.076 – 0.279)	0.161 (0.079 – 0.280)	0.158 (0.078 – 0.274)	0.160 (0.080 – 0.269)	0.155 (0.076 – 0.283)	0.152 (0.072 – 0.264)
Res_{01}	0.560 (0.419 – 0.688)	0.562 (0.428 – 0.691)	0.566 (0.437 – 0.694)	0.569 (0.435 – 0.696)	0.567 (0.431 – 0.701)	0.538 (0.413 – 0.667)
Res_{02}	0.620 (0.504 – 0.747)	0.631 (0.507 – 0.760)	0.637 (0.509 – 0.762)	0.646 (0.507 – 0.784)	0.654 (0.517 – 0.810)	0.727 (0.495 – 0.987)
$Surv_{pre}$	0.885 (0.857 – 0.909)	0.884 (0.858 – 0.908)	0.884 (0.859 – 0.906)	0.883 (0.858 – 0.905)	0.882 (0.857 – 0.905)	0.874 (0.855 – 0.893)
$Surv_{post}$	0.855 (0.816 – 0.891)	0.848 (0.804 – 0.889)	0.841 (0.790 – 0.892)	0.832 (0.767 – 0.894)	0.821 (0.737 – 0.903)	0.710 (0.490 – 0.980)
$Surv_{change}$	**-0.030 (-0.080 – 0.020)**	**-0.036 (-0.091 – 0.019)**	**-0.042 (-0.101 – 0.019)**	**-0.050 (-0.124 – 0.022)**	**-0.061 (-0.155 – 0.031)**	**-0.164 (-0.389 – 0.107)**

APPENDIX G: SEABIRD INPUT FILES

Input files for model run 1a (reference model run)

population.sbd

```
@n_classes 2
@classes M R
@initial 1986
@current 2002
@final 2002

@initialisation
parameter_map 2 1
parameter_names Const1 Const0

@annual_cycle
time_steps 2
surv_props 0.5 0.5
recruitment_time 1
transition_time 2

@survival
parameter_map 1 1
parameter_names d_surv

@transition
parameter_map 0          1          0          2
parameter_names trans_M_R trans_R_R

@selectivity_names sel_MR sel_R

@recruitment
classes M
parameter_names d_const_rec

@derived_parameter
name d_const_rec
formula b_const_rec

@derived_parameter
name Const0
formula 0

@derived_parameter
name Const1
formula 1

@resight_p hectors
parameter_map 1 2
parameter_names d_res_M d_res_R

@selectivity sel_MR
parameter_map 1 1
parameters 1

@selectivity sel_R
parameter_map 1 2
parameters 0 1
```

```
@derived_parameter
name            trans_M_R
formula 1

@derived_parameter
name            trans_R_R
formula 1

# BASE PARAMETERS

@base_parameter
name d_res_M
values 0

@base_parameter
name d_res_R
values      0.0  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.0  0.0  0.3  0.3  0.3
year_blocks 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002

@base_parameter
name d_surv
values      0.9  0.9
year_blocks 1986 1990


# TAG ONLY
@base_parameter
name b_const_rec
values      77   22     30     6      9      20     26     10     7      14     8      0      0      0      32     47
year_blocks 1986        1987   1988   1989   1990   1991   1992   1993   1994   1995   1996   1997   1998   1999   2000   2001
```

estimation.sbd

```
@estimator Bayes

@max_iters 500
@max_evals 1000
@grad_tol 0.0001

@MCMC
start 0
length 2000000
keep 1000
stepsize 0.05
adaptive_stepsize False
burn_in 0
proposal_t True
df 4

@mark_recapture hectors_banks
step 1
proportion_mortality 0
resight_p hectors
optimiser F
banded_1   1986   2002   1   2   2   2   0   0   2   2   2   2   0   2   – 1   – 1   0   2   0
banded_2   1986   2002   1   2   2   0   0   0   2   2   0   0   0   2   – 1   – 1   0   0   0
banded_3   1986   2002   1   2   2   0   0   2   0   0   2   2   2   0   – 1   – 1   0   0   0
banded_4   1986   2002   1   2   2   0   0   0   0   0   0   0   0   0   – 1   – 1   0   0   0
banded_5   1986   2002   1   2   2   0   0   0   0   0   0   0   0   0   – 1   – 1   0   0   0
banded_6   1986   2002   1   0   0   0   0   2   2   0   0   2   0   0   – 1   – 1   2   0   2
```

banded_7	1986	2002	1	2	2	2	0	2	0	2	2	2	2	0	– 1	– 1	0	0	2
banded_8	1986	2002	1	2	0	0	0	0	2	2	0	0	0	0	– 1	– 1	0	0	2
banded_9	1986	2002	1	0	2	0	0	2	0	2	0	0	0	0	– 1	– 1	0	0	2
banded_10	1986	2002	1	0	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	2
banded_11	1986	2002	1	2	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	2
banded_12	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	2
banded_13	1986	2002	1	0	2	0	0	0	0	2	0	2	0	0	– 1	– 1	0	2	0
banded_14	1986	2002	1	2	2	0	0	0	2	0	0	0	0	0	– 1	– 1	0	2	0
banded_15	1986	2002	1	0	2	0	0	0	0	0	0	0	2	2	– 1	– 1	2	0	0
banded_16	1986	2002	1	2	2	0	2	2	2	2	2	2	2	2	– 1	– 1	0	0	0
banded_17	1986	2002	1	2	2	0	2	0	2	2	0	0	0	2	– 1	– 1	0	0	0
banded_18	1986	2002	1	0	0	2	0	0	0	2	2	2	0	2	– 1	– 1	0	0	0
banded_19	1986	2002	1	0	2	0	0	0	0	0	0	0	2	0	– 1	– 1	0	0	0
banded_20	1986	2002	1	2	0	2	2	2	2	2	2	2	2	0	– 1	– 1	0	0	0
banded_21	1986	2002	1	0	2	0	0	0	0	2	2	2	0	0	– 1	– 1	0	0	0
banded_22	1986	2002	1	0	2	2	0	0	0	0	0	2	0	0	– 1	– 1	0	0	0
banded_23	1986	2002	1	2	2	0	0	2	2	0	2	2	0	0	– 1	– 1	0	0	0
banded_24	1986	2002	1	2	2	0	0	0	0	0	2	2	0	0	– 1	– 1	0	0	0
banded_25	1986	2002	1	0	0	2	0	0	0	0	0	2	0	0	– 1	– 1	0	0	0
banded_26	1986	2002	1	0	0	0	0	0	2	2	2	0	0	0	– 1	– 1	0	0	0
banded_27	1986	2002	1	2	2	2	2	2	0	0	2	0	0	0	– 1	– 1	0	0	0
banded_28	1986	2002	1	2	2	0	0	0	0	0	2	0	0	0	– 1	– 1	0	0	0
banded_29	1986	2002	1	0	0	0	0	0	0	0	2	0	0	0	– 1	– 1	0	0	0
banded_30	1986	2002	1	2	2	0	0	2	2	2	0	0	0	0	– 1	– 1	0	0	0
banded_31	1986	2002	1	0	2	0	0	0	2	2	0	0	0	0	– 1	– 1	0	0	0
banded_32	1986	2002	1	2	0	0	0	2	0	2	0	0	0	0	– 1	– 1	0	0	0
banded_33	1986	2002	1	2	2	0	0	2	2	0	0	0	0	0	– 1	– 1	0	0	0
banded_34	1986	2002	1	2	2	0	0	0	2	0	0	0	0	0	– 1	– 1	0	0	0
banded_35	1986	2002	1	0	0	0	0	0	2	0	0	0	0	0	– 1	– 1	0	0	0
banded_36	1986	2002	1	0	0	0	0	0	2	0	0	0	0	0	– 1	– 1	0	0	0
banded_37	1986	2002	1	2	2	0	0	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_38	1986	2002	1	0	2	0	2	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_39	1986	2002	1	2	2	2	0	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_40	1986	2002	1	2	0	0	0	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_41	1986	2002	1	0	0	0	0	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_42	1986	2002	1	0	0	0	0	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_43	1986	2002	1	0	0	0	0	2	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_44	1986	2002	1	2	2	2	2	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_45	1986	2002	1	2	2	0	2	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_46	1986	2002	1	2	2	0	2	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_47	1986	2002	1	2	2	2	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_48	1986	2002	1	2	2	2	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_49	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_50	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_51	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_52	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_53	1986	2002	1	0	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_54	1986	2002	1	0	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_55	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_56	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_57	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_58	1986	2002	1	2	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_59	1986	2002	1	0	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_60	1986	2002	1	0	2	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_61	1986	2002	1	2	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_62	1986	2002	1	2	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_63	1986	2002	1	2	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_64	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_65	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_66	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_67	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_68	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_69	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_70	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0
banded_71	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	– 1	– 1	0	0	0

banded_72	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0
banded_73	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0
banded_74	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0
banded_75	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0
banded_76	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0
banded_77	1986	2002	1	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0
banded_78	1987	2002	1	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_79	1987	2002	1	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_80	1987	2002	1	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_81	1987	2002	1	0	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_82	1987	2002	1	2	0	0	2	2	2	0	0	0	0	− 1	− 1	0	0	2	
banded_83	1987	2002	1	2	0	0	0	2	0	0	2	0	0	− 1	− 1	0	2	2	
banded_84	1987	2002	1	2	0	0	2	0	2	2	2	2	2	− 1	− 1	0	0	2	
banded_85	1987	2002	1	2	0	2	2	2	2	0	0	0	0	− 1	− 1	0	0	2	
banded_86	1987	2002	1	2	2	2	2	2	0	2	2	0	2	− 1	− 1	0	2	0	
banded_87	1987	2002	1	0	0	0	2	2	2	0	2	0	2	− 1	− 1	0	0	0	
banded_88	1987	2002	1	2	2	0	2	2	2	2	2	2	0	− 1	− 1	0	0	0	
banded_89	1987	2002	1	2	0	0	2	2	2	2	2	2	0	− 1	− 1	0	0	0	
banded_90	1987	2002	1	2	0	0	0	0	0	0	2	0	0	− 1	− 1	0	0	0	
banded_91	1987	2002	1	2	2	2	2	2	2	2	0	0	0	− 1	− 1	0	0	0	
banded_92	1987	2002	1	0	0	0	2	2	2	0	0	0	0	− 1	− 1	0	0	0	
banded_93	1987	2002	1	0	0	0	2	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_94	1987	2002	1	0	0	2	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_95	1987	2002	1	0	0	2	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_96	1987	2002	1	2	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_97	1987	2002	1	2	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_98	1987	2002	1	2	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_99	1987	2002	1	2	0	0	0	0	0	0	0	0	0	− 1	− 1	0	0	0	
banded_100	1988	2002	1	0	0	0	0	2	0	0	2	2	− 1	− 1	0	0	0		
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