

Preliminary migrate analysis of *M. californianus*

MIGRATION RATE AND POPULATION SIZE ESTIMATION

using the coalescent and maximum likelihood or Bayesian inference

Migrate-n version 3.7.2 [April-12-18]

Program started at Fri May 28 11:00:46 2021

Program finished at Fri May 28 14:49:43 2021



Options

Datatype:

DNA sequence data

Inheritance scalers in use for Thetas:

All loci use an inheritance scaler of 1.0

[The locus with a scaler of 1.0 used as reference]

Random number seed:

(with internal timer)

3412945191

Start parameters:

Theta values were generated

from guessed values

Theta = 0.01000

M values were generated

from guessed values

M-matrix:

100000.00 [all are the same]

Connection type matrix:

where m = average (average over a group of Thetas or M,

s = symmetric M, S = symmetric 4Nm, 0 = zero, and not estimated,

* = free to vary, Thetas are on diagonal

Population	1	2	3	4	5	6	7	8	9	10	11	12
1 ElfinCo	*	*	0	0	0	0	0	0	0	0	0	0
2 Bamfiel	*	*	*	0	0	0	0	0	0	0	0	0
3 PortRen	0	*	*	*	0	0	0	0	0	0	0	0
4 WalkOnB	0	0	*	*	*	0	0	0	0	0	0	0
5 BodegaH	0	0	0	*	*	*	0	0	0	0	0	0
6 Davenpo	0	0	0	0	*	*	*	0	0	0	0	0
7 VistaDe	0	0	0	0	0	*	*	*	0	0	0	0
8 HazardR	0	0	0	0	0	0	*	*	*	0	0	0
9 Refugio	0	0	0	0	0	0	0	*	*	*	0	0
10 Carpint	0	0	0	0	0	0	0	0	*	*	*	0

11 WhitePo	0	0	0	0	0	0	0	0	0	*	*	*
12	0	0	0	0	0	0	0	0	0	0	*	*

Order of parameters:

1	Θ_1	<displayed>
2	Θ_2	<displayed>
3	Θ_3	<displayed>
4	Θ_4	<displayed>
5	Θ_5	<displayed>
6	Θ_6	<displayed>
7	Θ_7	<displayed>
8	Θ_8	<displayed>
9	Θ_9	<displayed>
10	Θ_{10}	<displayed>
11	Θ_{11}	<displayed>
12	Θ_{12}	<displayed>
13	$M_{2 \rightarrow 1}$	<displayed>
24	$M_{1 \rightarrow 2}$	<displayed>
25	$M_{3 \rightarrow 2}$	<displayed>
36	$M_{2 \rightarrow 3}$	<displayed>
37	$M_{4 \rightarrow 3}$	<displayed>
48	$M_{3 \rightarrow 4}$	<displayed>
49	$M_{5 \rightarrow 4}$	<displayed>
60	$M_{4 \rightarrow 5}$	<displayed>
61	$M_{6 \rightarrow 5}$	<displayed>
72	$M_{5 \rightarrow 6}$	<displayed>
73	$M_{7 \rightarrow 6}$	<displayed>
84	$M_{6 \rightarrow 7}$	<displayed>
85	$M_{8 \rightarrow 7}$	<displayed>
96	$M_{7 \rightarrow 8}$	<displayed>
97	$M_{9 \rightarrow 8}$	<displayed>
108	$M_{8 \rightarrow 9}$	<displayed>
109	$M_{10 \rightarrow 9}$	<displayed>
120	$M_{9 \rightarrow 10}$	<displayed>
121	$M_{11 \rightarrow 10}$	<displayed>
132	$M_{10 \rightarrow 11}$	<displayed>
133	$M_{12 \rightarrow 11}$	<displayed>
144	$M_{11 \rightarrow 12}$	<displayed>

Mutation rate among loci:

Mutation rate is constant

Analysis strategy:

Bayesian inference

Proposal distributions for parameter

Parameter	Proposal
Theta	Metropolis sampling
M	Slice sampling

Prior distribution for parameter

Parameter	Prior	Minimum	Mean*	Maximum	Delta	Bins
Theta	Exp window	0.000010	0.010000	10.000000	1.000000	500
M	Exp window	0.000100	100000.000000	1000000.000000	100000.000000	500

Markov chain settings:

	Long chain
Number of chains	1
Recorded steps [a]	1000
Increment (record every x step [b])	100
Number of concurrent chains (replicates) [c]	3
Visited (sampled) parameter values [a*b*c]	300000
Number of discard trees per chain (burn-in)	100

Multiple Markov chains:

Static heating scheme	4 chains with temperatures
	100000.00 3.00 1.50 1.00
	Swapping interval is 1

Print options:

Data file:	../mcalifornianus_210528.mig
Output file:	outfile.txt
Posterior distribution raw histogram file:	bayesfile
Print data:	No
Print genealogies [only some for some data type]:	None

Data summary

Datatype: Sequence data
 Number of loci: 1

Population	Locus	Gene copies
1 ElfinCo	1	19
2 Bamfiel	1	23
3 PortRen	1	15
4 WalkOnB	1	16
5 BodegaH	1	7
6 Davenpo	1	17
7 VistaDe	1	19
8 HazardR	1	23
9 Refugio	1	16
10 Carpint	1	19
11 WhitePo	1	10
12	1	0
Total of all populations	1	184

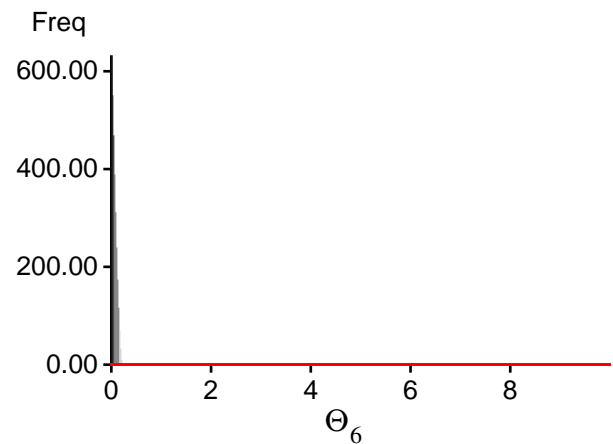
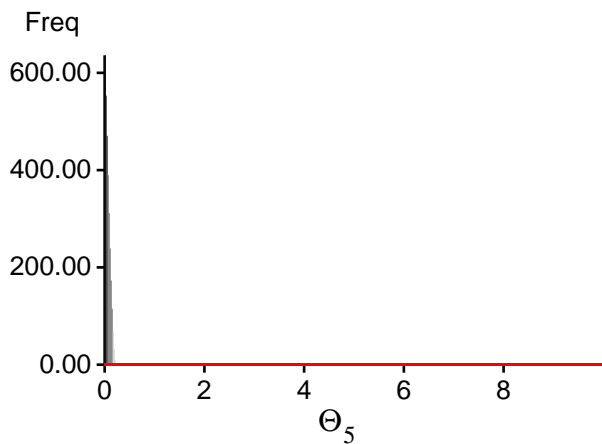
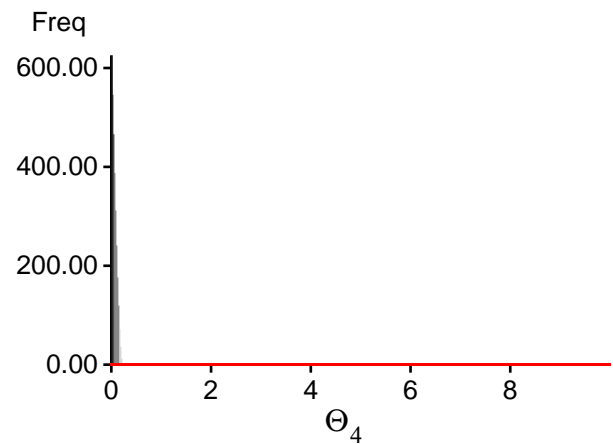
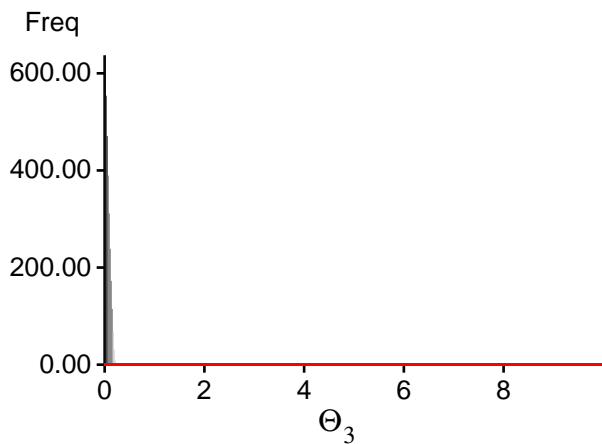
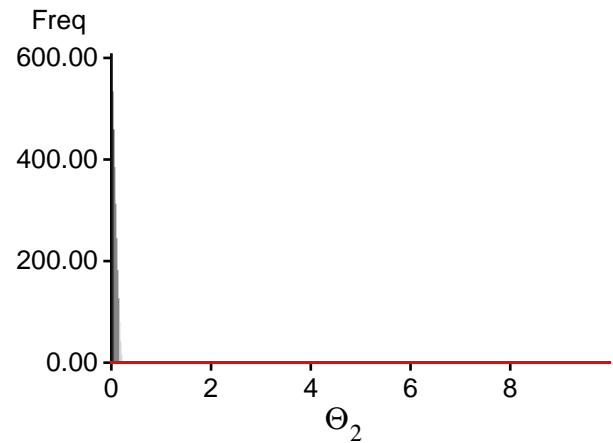
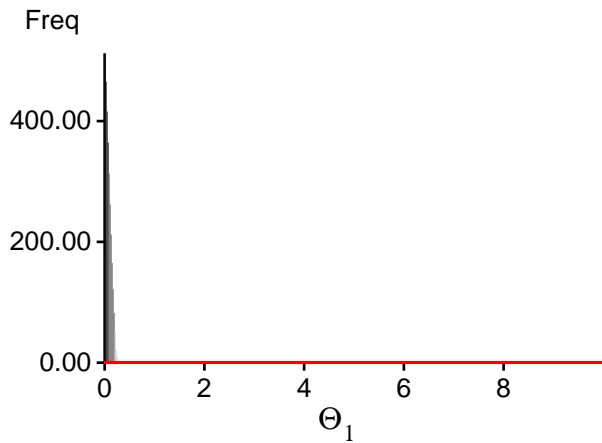
Bayesian Analysis: Posterior distribution table

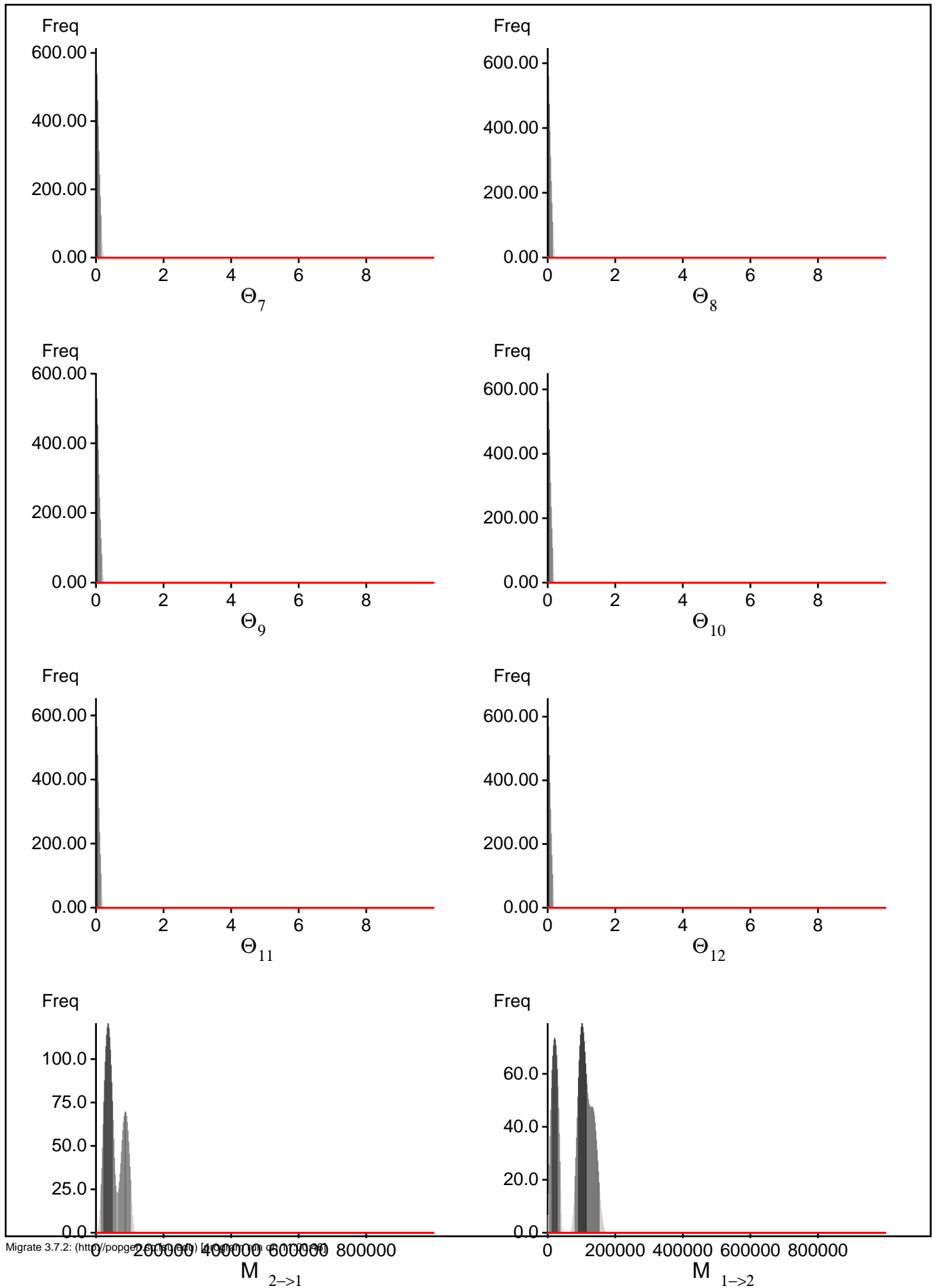
Locus	Parameter	2.5%	25.0%	Mode	75.0%	97.5%	Median	Mean
1	Θ_1	0.00001	0.00001	0.01001	0.08001	0.20001	0.09001	0.03741
1	Θ_2	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.02147
1	Θ_3	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01648
1	Θ_4	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01866
1	Θ_5	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01749
1	Θ_6	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01667
1	Θ_7	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01949
1	Θ_8	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01432
1	Θ_9	0.00001	0.00001	0.01001	0.06001	0.18001	0.07001	0.02746
1	Θ_{10}	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01451
1	Θ_{11}	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01106
1	Θ_{12}	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01040
1	$M_{2 \rightarrow 1}$	12000.0	20000.0	35000.0	50000.0	62000.0	47000.0	54286.7
1	$M_{1 \rightarrow 2}$	78000.0	88000.0	103000.0	116000.0	154000.0	101000.0	83222.2
1	$M_{3 \rightarrow 2}$	74000.0	102000.0	119000.0	132000.0	140000.0	103000.0	90234.3
1	$M_{2 \rightarrow 3}$	20000.0	34000.0	47000.0	56000.0	88000.0	51000.0	51037.3
1	$M_{4 \rightarrow 3}$	0.0	0.0	9000.0	22000.0	58000.0	45000.0	53243.4
1	$M_{3 \rightarrow 4}$	60000.0	74000.0	103000.0	118000.0	126000.0	85000.0	75887.7
1	$M_{5 \rightarrow 4}$	66000.0	80000.0	95000.0	112000.0	132000.0	89000.0	74201.4
1	$M_{4 \rightarrow 5}$	0.0	0.0	7000.0	18000.0	30000.0	107000.0	83905.8
1	$M_{6 \rightarrow 5}$	20000.0	66000.0	79000.0	92000.0	116000.0	79000.0	76107.8
1	$M_{5 \rightarrow 6}$	0.0	0.0	1000.0	14000.0	18000.0	47000.0	44622.2
1	$M_{7 \rightarrow 6}$	6000.0	14000.0	29000.0	42000.0	74000.0	37000.0	38526.4
1	$M_{6 \rightarrow 7}$	0.0	0.0	1000.0	18000.0	66000.0	21000.0	24234.9
1	$M_{8 \rightarrow 7}$	56000.0	72000.0	87000.0	96000.0	120000.0	89000.0	87807.8
1	$M_{7 \rightarrow 8}$	24000.0	34000.0	47000.0	82000.0	96000.0	77000.0	88331.6
1	$M_{9 \rightarrow 8}$	0.0	0.0	1000.0	12000.0	18000.0	15000.0	34494.4
1	$M_{8 \rightarrow 9}$	0.0	0.0	13000.0	24000.0	58000.0	41000.0	46713.7
1	$M_{10 \rightarrow 9}$	0.0	0.0	9000.0	22000.0	78000.0	23000.0	24444.4
1	$M_{9 \rightarrow 10}$	0.0	0.0	7000.0	16000.0	50000.0	17000.0	14623.8
1	$M_{11 \rightarrow 10}$	0.0	6000.0	21000.0	34000.0	44000.0	31000.0	40559.6
1	$M_{10 \rightarrow 11}$	54000.0	66000.0	81000.0	92000.0	150000.0	81000.0	65937.6
1	$M_{12 \rightarrow 11}$	68000.0	78000.0	95000.0	110000.0	122000.0	89000.0	71730.4
1	$M_{11 \rightarrow 12}$	90000.0	100000.0	123000.0	146000.0	156000.0	235000.0	242559.9

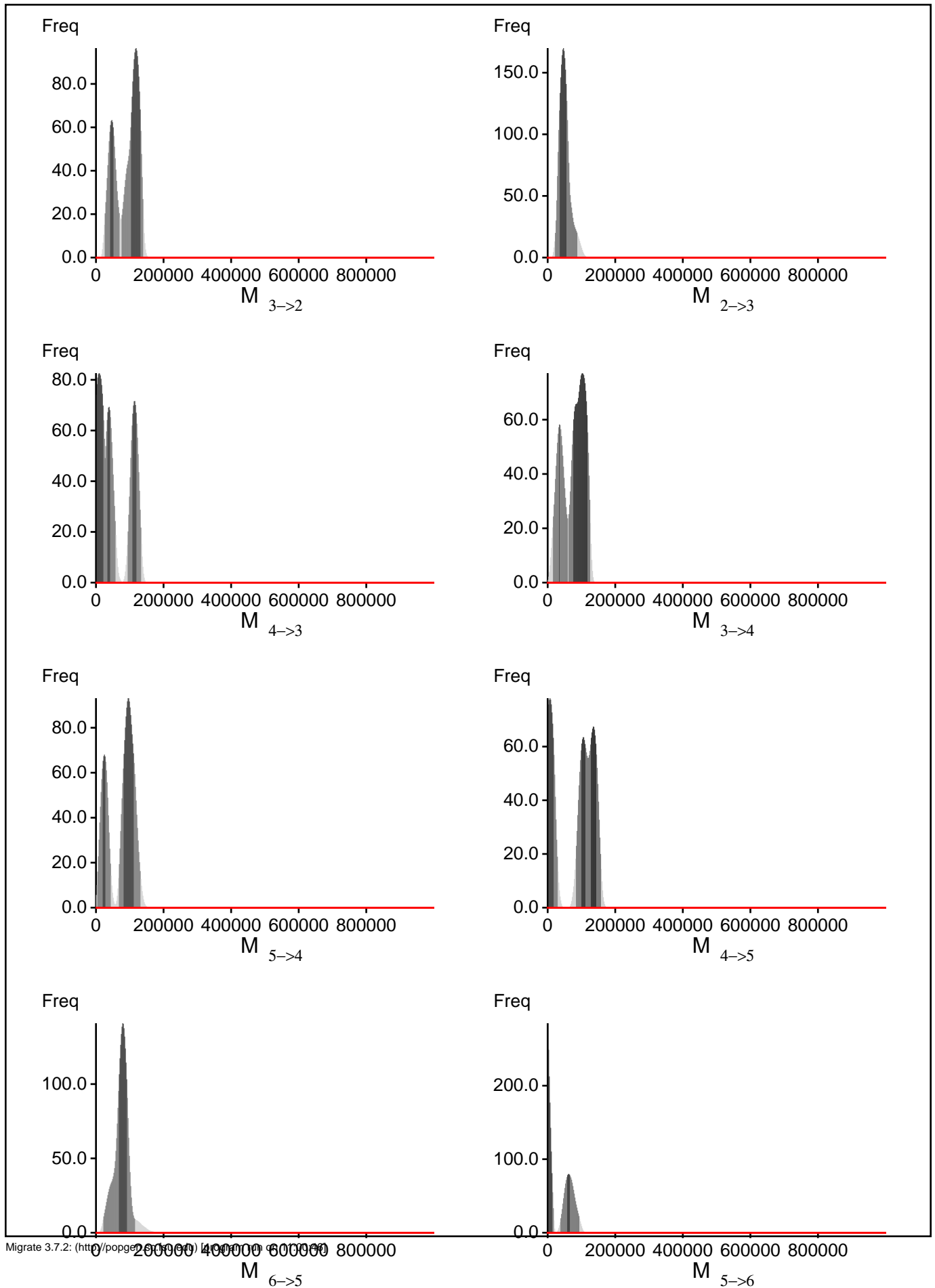
Citation suggestions:

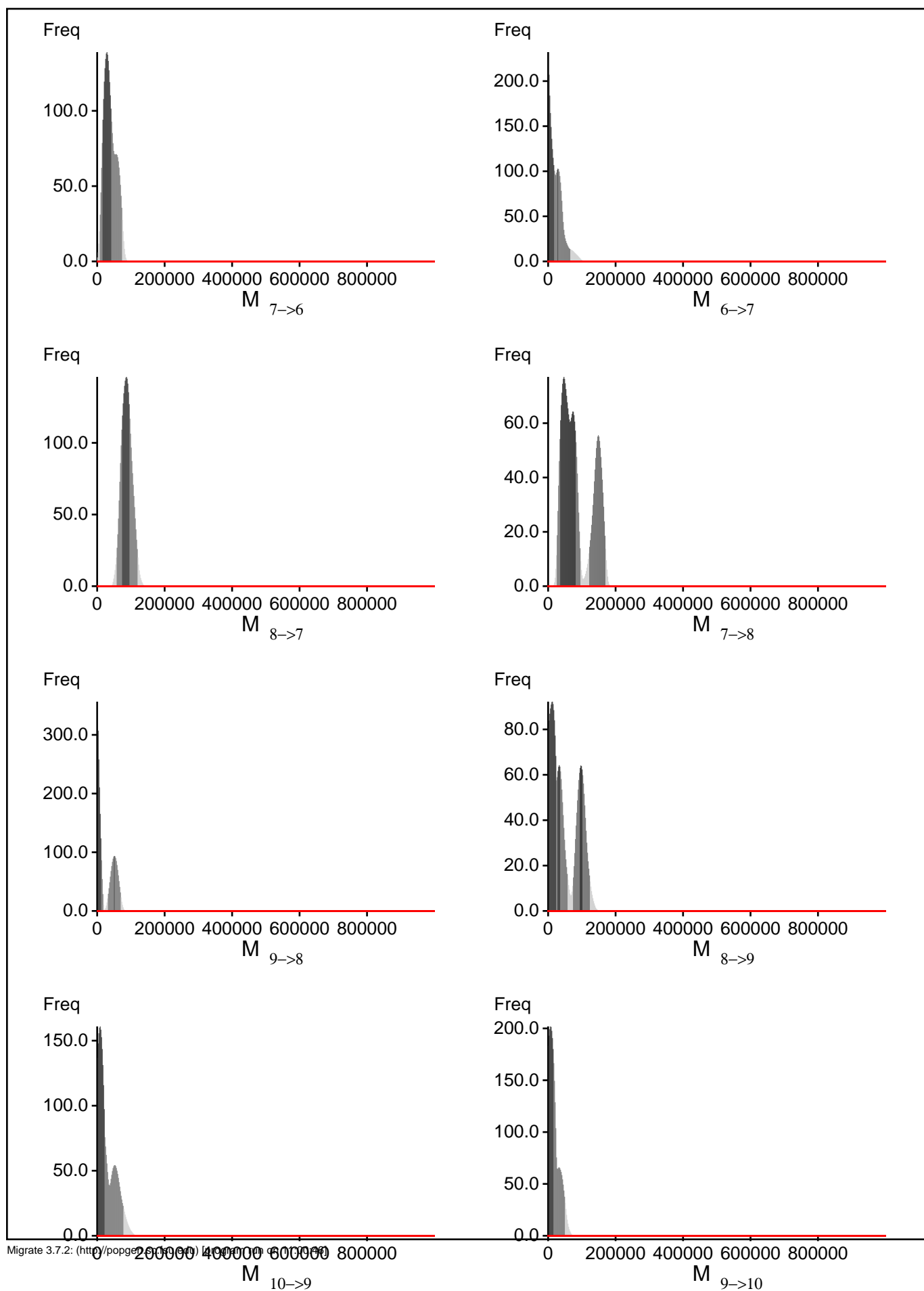
- Beerli P., 2006. Comparison of Bayesian and maximum-likelihood inference of population genetic parameters. *Bioinformatics* 22:341-345
- Beerli P., 2007. Estimation of the population scaled mutation rate from microsatellite data, *Genetics*, 177:1967-1968.
- Beerli P., 2009. How to use MIGRATE or why are Markov chain Monte Carlo programs difficult to use? In *Population Genetics for Animal Conservation*, G. Bertorelle, M. W. Bruford, H. C. Hauffe, A. Rizzoli, and C. Vernesi, eds., vol. 17 of *Conservation Biology*, Cambridge University Press, Cambridge UK, pp. 42-79.

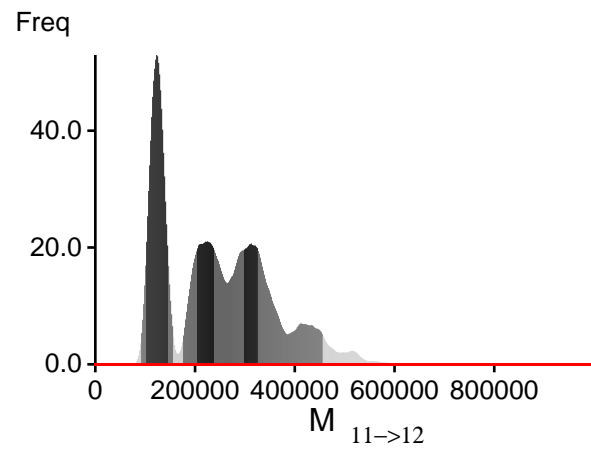
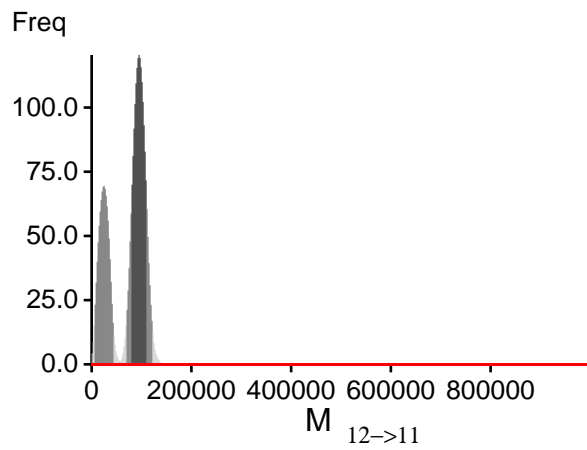
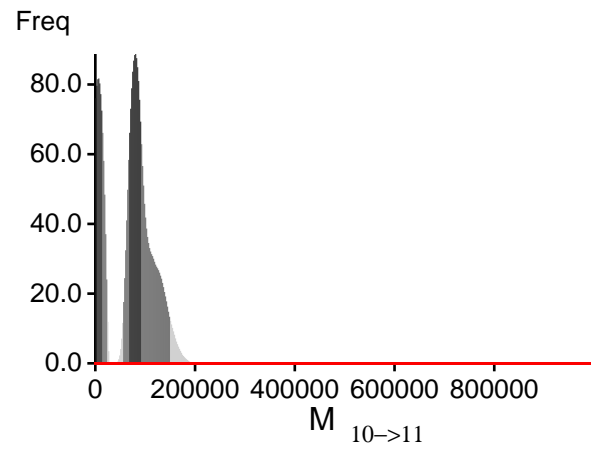
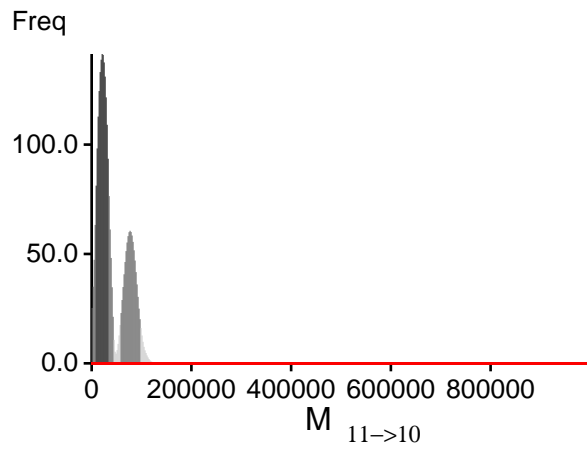
Bayesian Analysis: Posterior distribution over all loci











Log-Probability of the data given the model (marginal likelihood)

Use this value for Bayes factor calculations:

$BF = \text{Exp}[\ln(\text{Prob}(D \mid \text{thisModel}) - \ln(\text{Prob}(D \mid \text{otherModel}))]$

or as $LBF = 2 (\ln(\text{Prob}(D \mid \text{thisModel}) - \ln(\text{Prob}(D \mid \text{otherModel})))$

shows the support for thisModel]

Method	$\ln(\text{Prob}(D \mid \text{Model}))$	Notes
Thermodynamic integration	-2182.125069	(1a)
	-2106.873594	(1b)
Harmonic mean	-2095.766814	(2)

(1a, 1b and 2) are approximations to the marginal likelihood, make sure that the program run long enough!

(1a, 1b) and (2) should give similar results, in principle.

But (2) is overestimating the likelihood, it is presented for historical reasons and should not be used

(1a, 1b) needs heating with chains that span a temperature range of 1.0 to at least 100,000.

(1b) is using a Bezier-curve to get better approximations for runs with low number of heated chains

Citation suggestions:

Beerli P. and M. Palczewski, 2010. Unified framework to evaluate panmixia and migration direction among multiple sampling locations, *Genetics*, 185: 313-326.

Acceptance ratios for all parameters and the genealogies

Parameter	Accepted changes	Ratio
Θ_1	760/4405	0.17253
Θ_2	1294/4414	0.29316
Θ_3	1004/4494	0.22341
Θ_4	1708/4373	0.39058
Θ_5	2164/4335	0.49919
Θ_6	1386/4435	0.31251
Θ_7	753/4402	0.17106
Θ_8	1283/4398	0.29172
Θ_9	1588/4317	0.36785
Θ_{10}	1567/4513	0.34722
Θ_{11}	1361/4399	0.30939
Θ_{12}	3092/4470	0.69172
$M_{2 \rightarrow 1}$	4458/4458	1.00000
$M_{1 \rightarrow 2}$	4319/4319	1.00000
$M_{3 \rightarrow 2}$	4345/4345	1.00000
$M_{2 \rightarrow 3}$	4510/4510	1.00000
$M_{4 \rightarrow 3}$	4485/4485	1.00000
$M_{3 \rightarrow 4}$	4427/4427	1.00000
$M_{5 \rightarrow 4}$	4455/4455	1.00000
$M_{4 \rightarrow 5}$	4457/4457	1.00000
$M_{6 \rightarrow 5}$	4382/4382	1.00000
$M_{5 \rightarrow 6}$	4446/4446	1.00000
$M_{7 \rightarrow 6}$	4494/4494	1.00000
$M_{6 \rightarrow 7}$	4508/4508	1.00000
$M_{8 \rightarrow 7}$	4372/4372	1.00000
$M_{7 \rightarrow 8}$	4418/4418	1.00000
$M_{9 \rightarrow 8}$	4307/4307	1.00000
$M_{8 \rightarrow 9}$	4583/4583	1.00000
$M_{10 \rightarrow 9}$	4435/4435	1.00000
$M_{9 \rightarrow 10}$	4406/4406	1.00000
$M_{11 \rightarrow 10}$	4529/4529	1.00000
$M_{10 \rightarrow 11}$	4273/4273	1.00000
$M_{12 \rightarrow 11}$	4399/4399	1.00000
$M_{11 \rightarrow 12}$	4401/4401	1.00000
Genealogies	44124/149636	0.29488

MCMC-Autocorrelation and Effective MCMC Sample Size

Parameter	Autocorrelation	Effective Sample Size
Θ_1	0.90169	163.56
Θ_2	0.83291	276.27
Θ_3	0.82089	306.60
Θ_4	0.75514	423.71
Θ_5	0.62299	712.58
Θ_6	0.78011	381.07
Θ_7	0.87045	216.48
Θ_8	0.77834	386.08
Θ_9	0.72605	519.01
Θ_{10}	0.76286	422.27
Θ_{11}	0.73812	487.98
Θ_{12}	0.45006	1170.82
$M_{2 \rightarrow 1}$	0.89102	176.05
$M_{1 \rightarrow 2}$	0.78497	377.34
$M_{3 \rightarrow 2}$	0.84362	260.60
$M_{2 \rightarrow 3}$	0.83097	283.12
$M_{4 \rightarrow 3}$	0.79869	342.36
$M_{3 \rightarrow 4}$	0.69120	604.49
$M_{5 \rightarrow 4}$	0.85770	230.04
$M_{4 \rightarrow 5}$	0.80162	332.82
$M_{6 \rightarrow 5}$	0.85232	243.47
$M_{5 \rightarrow 6}$	0.85043	243.94
$M_{7 \rightarrow 6}$	0.77918	377.57
$M_{6 \rightarrow 7}$	0.83572	279.83
$M_{8 \rightarrow 7}$	0.87316	203.72
$M_{7 \rightarrow 8}$	0.83877	265.84
$M_{9 \rightarrow 8}$	0.76303	405.71
$M_{8 \rightarrow 9}$	0.80880	316.96
$M_{10 \rightarrow 9}$	0.87810	194.59
$M_{9 \rightarrow 10}$	0.65191	776.18
$M_{11 \rightarrow 10}$	0.81274	315.33
$M_{10 \rightarrow 11}$	0.83533	277.40
$M_{12 \rightarrow 11}$	0.78393	376.90
$M_{11 \rightarrow 12}$	0.87850	197.01
Ln[Prob(D G)]	0.99425	8.64

Potential Problems

This section reports potential problems with your run, but such reporting is often not very accurate. With many parameters in a multilocus analysis, it is very common that some parameters for some loci will not be very informative, triggering suggestions (for example to increase the prior range) that are not sensible. This suggestion tool will improve with time, therefore do not blindly follow its suggestions. If some parameters are flagged, inspect the tables carefully and judge whether an action is required. For example, if you run a Bayesian inference with sequence data, for macroscopic species there is rarely the need to increase the prior for Theta beyond 0.1; but if you use microsatellites it is rather common that your prior distribution for Theta should have a range from 0.0 to 100 or more. With many populations (>3) it is also very common that some migration routes are estimated poorly because the data contains little or no information for that route. Increasing the range will not help in such situations, reducing number of parameters may help in such situations.

No warning was recorded during the run