

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 Wed Jun 2 17:54:48 2021

Program finished at Wed Jun 2 18:25:31 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)

892504957

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

11 WhitePo	0	0	0	0	0	0	0	0	0	*	*	0
12 LaJolla	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>
24	$M_{1 \rightarrow 2}$	<displayed>
36	$M_{2 \rightarrow 3}$	<displayed>
48	$M_{3 \rightarrow 4}$	<displayed>
60	$M_{4 \rightarrow 5}$	<displayed>
72	$M_{5 \rightarrow 6}$	<displayed>
84	$M_{6 \rightarrow 7}$	<displayed>
96	$M_{7 \rightarrow 8}$	<displayed>
108	$M_{8 \rightarrow 9}$	<displayed>
120	$M_{9 \rightarrow 10}$	<displayed>
132	$M_{10 \rightarrow 11}$	<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)	1000			
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	11
12 LaJolla	1	8
Total of all populations	1	193

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	0.18001	0.09001	0.03033
1	Θ_2	0.00001	0.00001	0.01001	0.08001	0.20001	0.09001	0.03572
1	Θ_3	0.00001	0.00001	0.01001	0.06001	0.18001	0.07001	0.02336
1	Θ_4	0.00001	0.00001	0.01001	0.08001	0.20001	0.09001	0.03609
1	Θ_5	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.02196
1	Θ_6	0.00001	0.00001	0.01001	0.06001	0.18001	0.07001	0.02343
1	Θ_7	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01935
1	Θ_8	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01073
1	Θ_9	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01525
1	Θ_{10}	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.02177
1	Θ_{11}	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.01338
1	Θ_{12}	0.00001	0.00001	0.01001	0.06001	0.16001	0.07001	0.00749
1	$M_{1 \rightarrow 2}$	0.0	0.0	3000.0	18000.0	46000.0	19000.0	13860.5
1	$M_{2 \rightarrow 3}$	0.0	0.0	13000.0	26000.0	38000.0	25000.0	73083.6
1	$M_{3 \rightarrow 4}$	0.0	0.0	7000.0	14000.0	24000.0	13000.0	7273.6
1	$M_{4 \rightarrow 5}$	0.0	0.0	1000.0	16000.0	22000.0	91000.0	77000.5
1	$M_{5 \rightarrow 6}$	0.0	0.0	15000.0	28000.0	84000.0	27000.0	31160.2
1	$M_{6 \rightarrow 7}$	0.0	8000.0	19000.0	26000.0	40000.0	21000.0	19581.8
1	$M_{7 \rightarrow 8}$	22000.0	38000.0	55000.0	78000.0	128000.0	69000.0	71821.5
1	$M_{8 \rightarrow 9}$	0.0	0.0	17000.0	34000.0	140000.0	35000.0	50447.4
1	$M_{9 \rightarrow 10}$	0.0	0.0	7000.0	20000.0	74000.0	21000.0	22116.8
1	$M_{10 \rightarrow 11}$	0.0	2000.0	15000.0	26000.0	78000.0	23000.0	25785.4
1	$M_{11 \rightarrow 12}$	38000.0	52000.0	127000.0	264000.0	422000.0	253000.0	382187.9

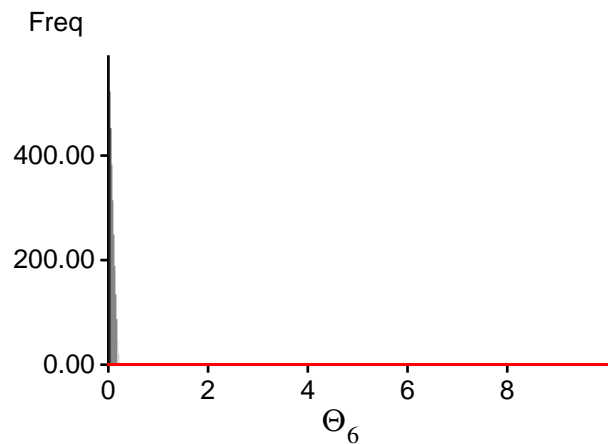
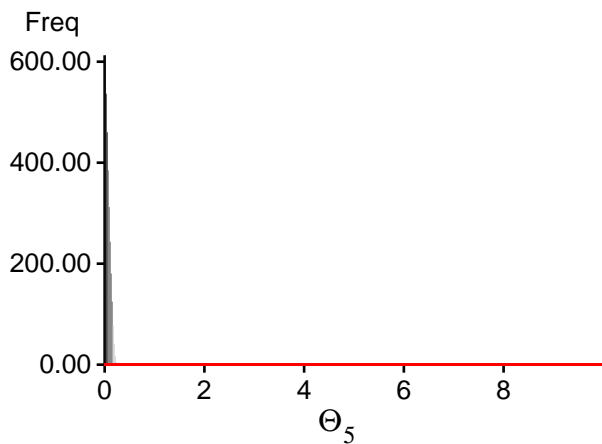
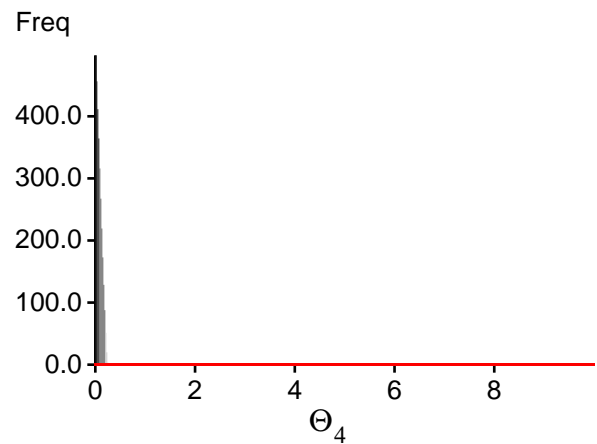
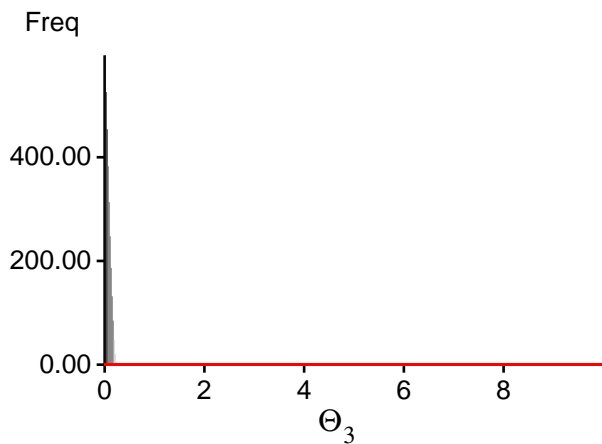
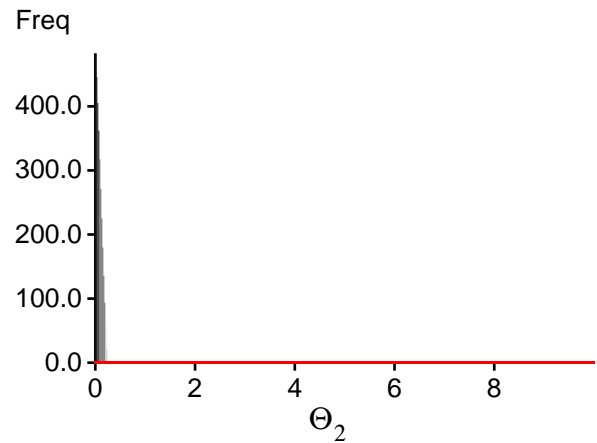
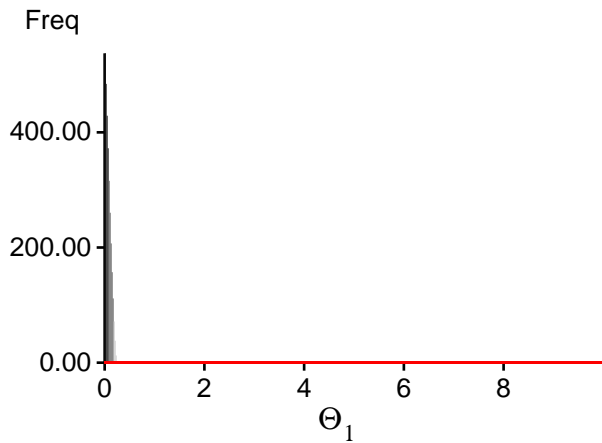
Citation suggestions:

Beerli P., 2006. Comparison of Bayesian and maximum-likelihood inference of population genetic parameters. *Bioinformatics* 22:341-345

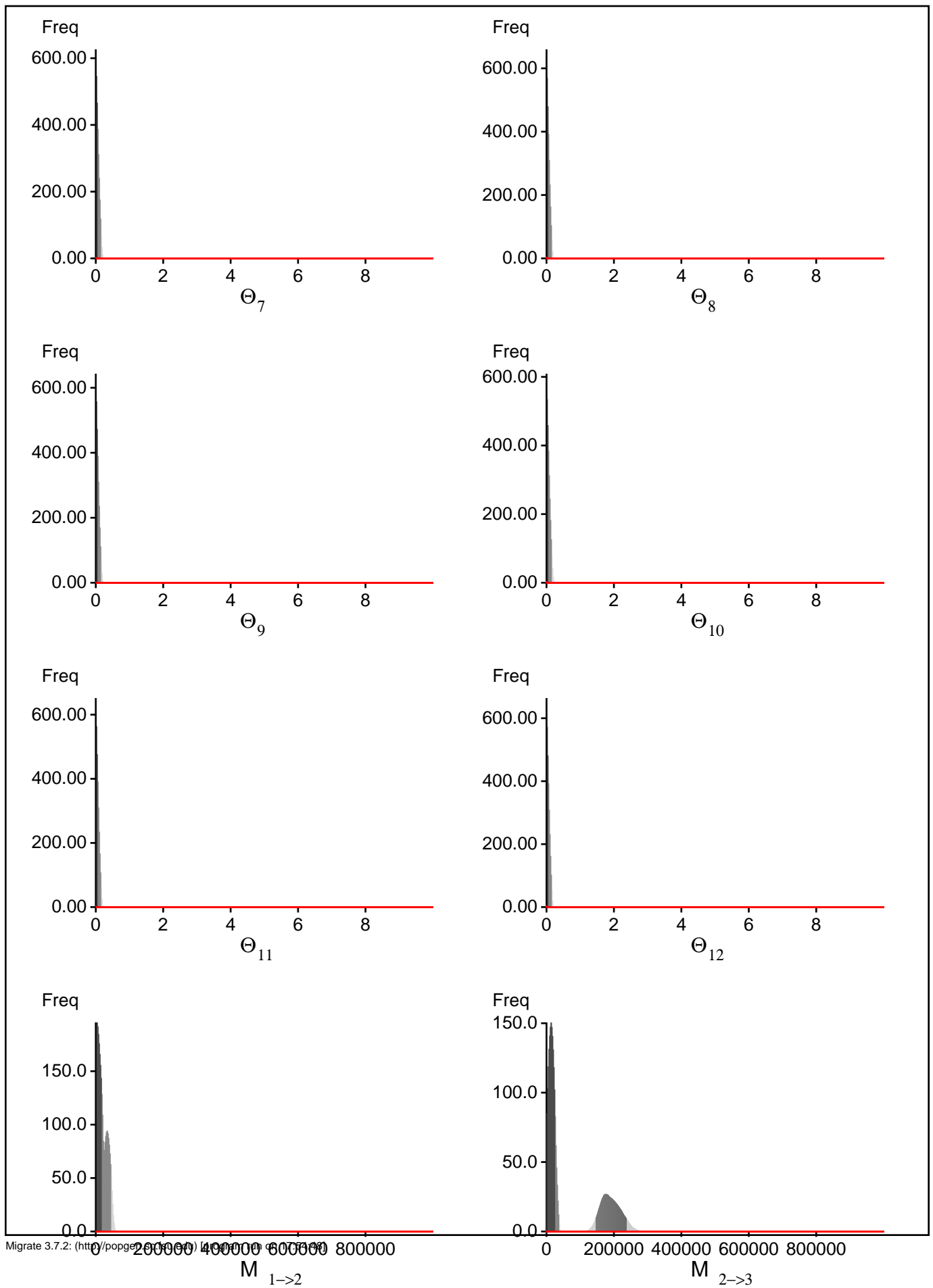
Beerli P., 2007. Estimation of the population scaled mutation rate from microsatellite data, *Genetics*, 177:1967-1968.

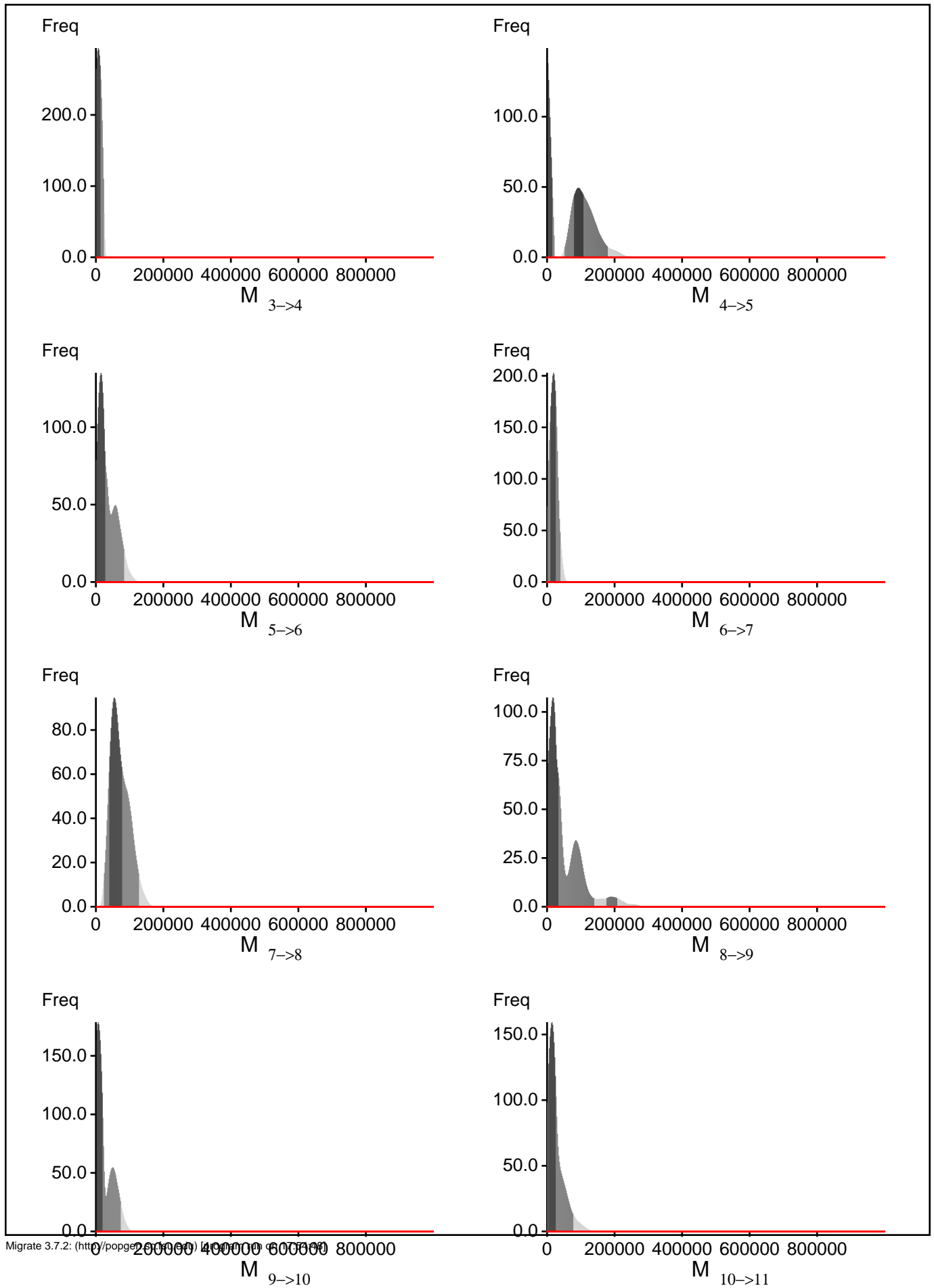
Beerli P., 2009. How to use MIGRATE or why are Markov chain Monte Carlo programs difficult to use? In *Population Genetics for Animal Conservation*, G. Bertorelle, M. W. Bruford, H. C. Hauffe, A. Rizzoli, and C. Vernesi, eds., vol. 17 of *Conservation Biology*, Cambridge University Press, Cambridge UK, pp. 42-79.

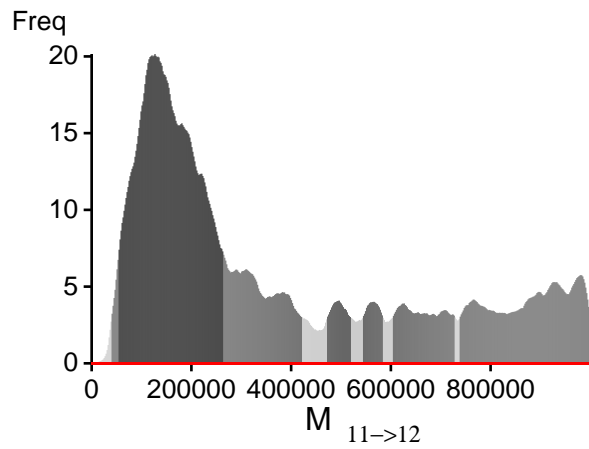
Bayesian Analysis: Posterior distribution over all loci



Preliminary migrate analysis of *M. californianus* CO1 haplotypes for Evolution 2 -- 7







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	-2209.814208	(1a)
	-2136.702616	(1b)
Harmonic mean	-1880.966017	(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	306/6543	0.04677
Θ_2	922/6529	0.14122
Θ_3	2664/6592	0.40413
Θ_4	818/6490	0.12604
Θ_5	3358/6636	0.50603
Θ_6	2064/6645	0.31061
Θ_7	2093/6484	0.32279
Θ_8	3829/6536	0.58583
Θ_9	3360/6466	0.51964
Θ_{10}	2490/6518	0.38202
Θ_{11}	3792/6475	0.58564
Θ_{12}	4882/6643	0.73491
$M_{1 \rightarrow 2}$	6594/6594	1.00000
$M_{2 \rightarrow 3}$	6514/6514	1.00000
$M_{3 \rightarrow 4}$	6503/6503	1.00000
$M_{4 \rightarrow 5}$	6513/6513	1.00000
$M_{5 \rightarrow 6}$	6452/6452	1.00000
$M_{6 \rightarrow 7}$	6512/6512	1.00000
$M_{7 \rightarrow 8}$	6555/6555	1.00000
$M_{8 \rightarrow 9}$	6517/6517	1.00000
$M_{9 \rightarrow 10}$	6459/6459	1.00000
$M_{10 \rightarrow 11}$	6475/6475	1.00000
$M_{11 \rightarrow 12}$	6356/6356	1.00000
Genealogies	37490/149993	0.24994

MCMC-Autocorrelation and Effective MCMC Sample Size

Parameter	Autocorrelation	Effective Sample Size
Θ_1	0.96030	61.98
Θ_2	0.82242	322.40
Θ_3	0.59984	963.60
Θ_4	0.90613	148.83
Θ_5	0.52528	1066.06
Θ_6	0.68428	597.99
Θ_7	0.72387	480.69
Θ_8	0.41093	1258.24
Θ_9	0.50647	1050.42
Θ_{10}	0.60229	798.43
Θ_{11}	0.39178	1318.11
Θ_{12}	0.24799	1868.31
$M_{1 \rightarrow 2}$	0.61529	717.91
$M_{2 \rightarrow 3}$	0.66762	598.43
$M_{3 \rightarrow 4}$	0.77088	393.78
$M_{4 \rightarrow 5}$	0.80039	339.24
$M_{5 \rightarrow 6}$	0.78857	356.72
$M_{6 \rightarrow 7}$	0.73527	462.21
$M_{7 \rightarrow 8}$	0.75290	434.32
$M_{8 \rightarrow 9}$	0.75449	429.33
$M_{9 \rightarrow 10}$	0.73627	459.49
$M_{10 \rightarrow 11}$	0.72277	498.87
$M_{11 \rightarrow 12}$	0.54097	931.63
$\text{Ln}[\text{Prob}(D G)]$	0.97560	37.02

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