Epidemiology & Infection

Meningococcal carriage by age in the African meningitis belt: a systematic review and meta-analysis

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Supplementary Material

Additional data files available online:

Cooper_et_al_2019_HYG_carriage_by_age.csv

Model predictions and 95% confidence intervals for capsulated meningococcal carriage by age in years and season.

Cooper_et_al_2019_HYG_carriage_data.csv

Raw data collected from systematic review and used in meta-analysis.

Figure S1. Rainfall patterns at study sites compared with model definition of rainy season (black shading). Climactic outliers at bottom, marked with asterisk.
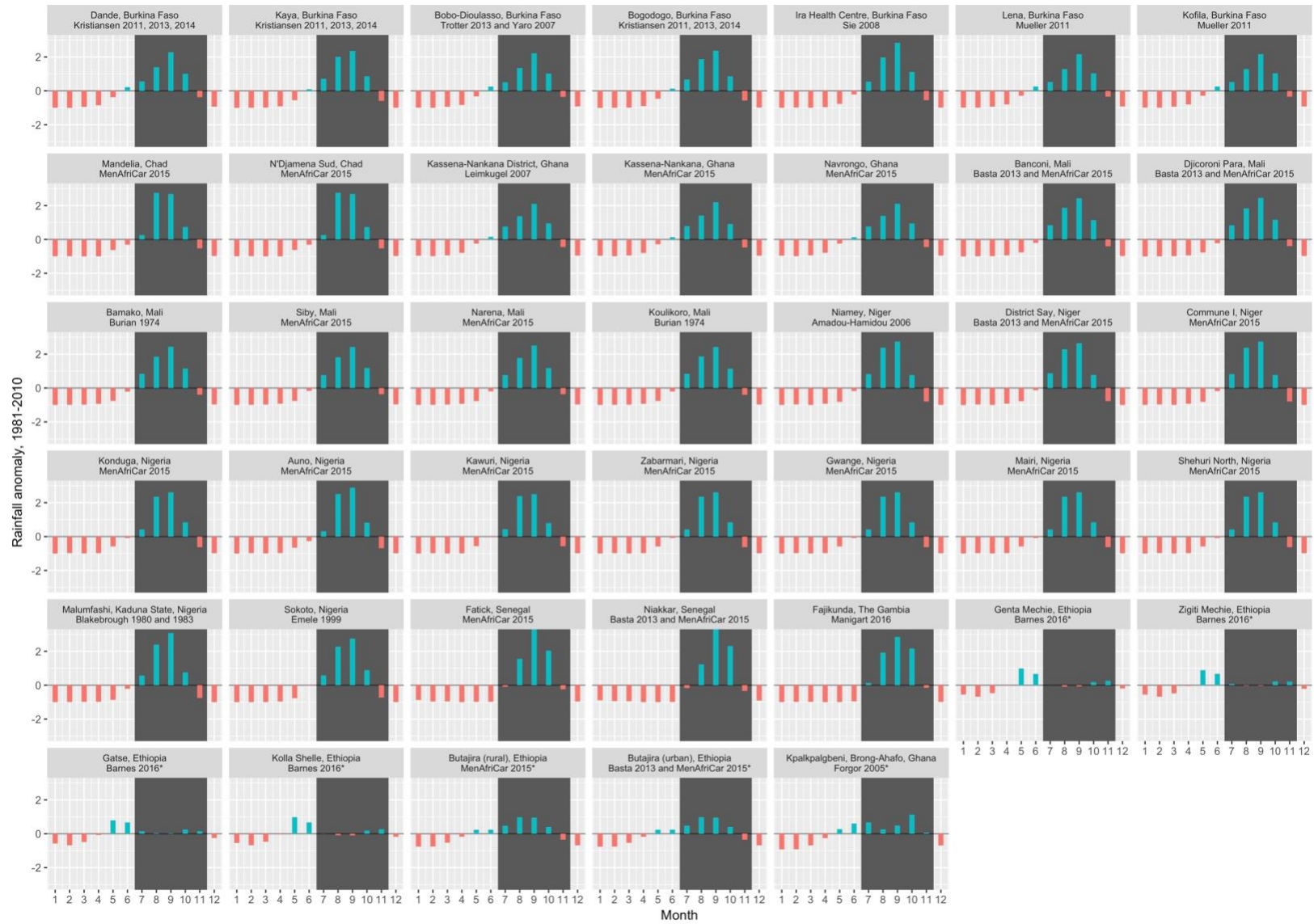
Table S1. Summary of papers included in systematic review.

Paper	Reason for exclusion from meta-analysis	Location	Study period	Study design	Study population	Random sample	Laboratory methods	Ages
Burian et al 1974		Bamako, Mali	Jan to May 1970	Cross-sectional	School children, children seen at preventative care centers, contacts of cases	No	Culture	All ages
Sanborn et al 1971	Wide age range	Northern Nigeria	Feb to Mar 1971	Vaccine trial	Both polysaccharide vaccinees and controls (vaccine had no impact on carriage)	No	Culture	5 to 15
Etienne et al 1973	Wide age range	Bobo-Dioulasso, Burkina Faso	Feb 1972 to Feb 1973	Longitudinal	General	No	Culture	All ages
Blakebrough et al 1982	Wide age range	Malumfashi, Nigeria	Apr 1976 to Oct 1977	Cross-sectional	School children	No	Culture	4 to 16
Blakebrough et al 1980		Malumfashi, Nigeria	Dec 1977 to Jun 1978	Cross-sectional	School children	No	Culture	5 to 10
Blakebrough et al 1983		Malumfashi, Nigeria	Jan to May 1978	Vaccine trial	School children (boys), both controls and polysaccharide vaccinees	Yes, within selected school	Culture	11 to 20
Emele et al 1999	Spanning both seasons	Sokoto, Nigeria	Nov 1990 to Mar 1992	Serial cross-sectional	General	No	Culture	1 to 19
Leimkugel et al 2007		Navrongo, Ghana	Apr 1998 to Nov 2005	Longitudinal	General	Yes	Culture with PCR confirmation	All ages
MacLennan et al 2000	Conjugate vaccine trial	Senegal and the Gambia		Vaccine trial	Children receiving conjugate vaccine	No	Culture with PCR confirmation	5
Raghunathan et al 2006	Wide age range	Dedougou and Yako, Burkina Faso	May 2002	Cross-sectional	General	Yes	Culture	5 to 25
Amadou Hamidou et al 2006		Niamey, Niger	Feb to May 2003	Longitudinal	School children	No	Culture	7 to 16
Yaro et al 2007		Bobo-Dioulasso, Burkina Faso	Feb to Jun 2003	Longitudinal	General	Yes	Culture with PCR confirmation	4 to 29
Forgor et al 2005	Excluded in climactic sensitivity analysis	Kpalkpalgbeni, Ghana	Apr 2003 to Apr 2004	Serial cross-sectional	General	No	Culture with PCR confirmation	All ages
Mueller et al 2011		Ouagadougou, Burkina Faso	Mar 2006	Cross-sectional	General	Yes, within selected village	Culture with PCR confirmation	1 to 39
Sie et al 2008	No sample size by age group	Nouna Health District, Burkina Faso	May 2006	Cross-sectional	General	Yes	Culture with PCR confirmation	All ages
Trotter et al 2013		Bobo-Dioulasso, Burkina Faso	Mar 2008	Cross-sectional	General	Yes	Culture with PCR confirmation	0 to 59
Kristiansen et al 2011		Bogodogo, Dande, and Kaya, Burkina Faso	Feb to Nov 2009	Serial cross-sectional	General	Yes		1 to 29
Basta et al 2013		Bamako, Mali; Butajira, Ethiopia; Niakkar, Senegal; Say, Niger	Jun 2009 to Jan 2010	Cross-sectional	School children	No	Culture with PCR confirmation	5 to 15

Table S1 (continued). Summary of papers included in systematic review.

Paper	Reason for exclusion from meta-analysis	Location	Study period	Study design	Study population	Random sample	Laboratory methods	Ages
MenAfriCar Consortium 2015		Bamako, Mali; Narena and Siby, Mali; Butajira, Ethiopia*; Fatick, Senegal; Niakkar, Senegal; Kassena-Nankana (rural site), Ghana; Navrongo, Ghana; Konduga, Nigeria; Maiduguri, Nigeria; Mandelia, Chad; N'Djamena, Chad; Say, Niger; Yantala, Niger	Apr 2010 to Jul 2012	Serial cross-sectional	General	Yes	Culture with PCR confirmation	All ages
Kristiansen et al 2013		Bogodogo, Dande, and Kaya, Burkina Faso	Oct 2010 to Nov 2011	Serial cross-sectional	General	Yes	Culture with PCR confirmation	1 to 29
Kristiansen et al 2014		Bogodogo, Dande, and Kaya, Burkina Faso	Oct to Nov 2012	Cross-sectional	General	Yes	Culture with PCR confirmation	1 to 29
Manigart et al 2016		Fajikunda, the Gambia	Jul 2013	Cross-sectional	General	No	Culture with PCR confirmation	10 to 18
Barnes et al 2016	Excluded in climactic sensitivity analysis	Arba Minch, Ethiopia	Mar to Sep 2014	Cross-sectional	General	No	Culture with PCR confirmation	1 to 29

*Observations excluded in sensitivity analysis – climactic outlier sites.

Table S2. Details of papers excluded from meta-analysis.

Paper	Reason for exclusion from meta-analysis	Study design	Study population	Location	Study sub-period	Age group	Number positive	Number sampled	Prevalence (%)
Sanborn et al 1971	Wide age range	Vaccine trial	Group A polysaccharide vaccinees and controls	Northern Nigeria, Nigeria	Early February 1971	5 to 15	179	311	57.6
Etienne et al 1973	Wide age range	Longitudinal	General	Bobo-Dioulasso, Burkina Faso	February 1972	0 to 14	13	63	20.4
						15 plus	11	32	34.2
Blakebrough et al 1982	Wide age range	Cross-sectional	School children	Malumfashi, Kaduna State, Nigeria	April 1976	4 to 16	8	107	7.5
					August 1976	4 to 16	7	104	6.7
					October 1977	4 to 16	53	631	8.4
Raghunathan et al 2006	Wide age range	Cross-sectional	Non-epidemic district	Dedougou, Burkina Faso	May 2002	5 to 25	75	439	17.1
	Wide age range		Epidemic district	Yako, Burkina Faso			128	460	27.8
Emele et al 1999	Spanning both seasons	Serial cross-sectional	General	Sokoto, Nigeria	November 1990 to March 1992	1 to 4	8	95	8.4
						5 to 9	23	270	8.5
						10 to 14	13	303	4.3
						15 to 19	1	58	1.7
MacLennan et al 2000	Conjugate vaccine trial	Vaccine trial	Children receiving conjugate vaccine	Senegal and the Gambia	1997	5	43	510	8.4
Sie et al 2008	No sample size by age group	Cross-sectional	General	Nouna Health District, Burkina Faso	May 20061	1 to 4	7		
						5 to 9	5		
						10 to 14	4		
						15 to 19	2		
						20 to 29	4		
						30 to 39	0		
						40 plus	1		

Table S3. Summary of model variants.

| Model type | Fixed effects odds ratios (95% CI) Natural cubic spline of age | | | | Dry season | Outbreak season | AIC* | Log-likelihood | LOOCV§ |
	I	II	III	IV					
Simple logistic	3.4 (2.9-4.0)	2.0 (1.7-2.4)	5.2 (3.7-7.2)	0.79 (0.71-0.87)	1.5 (1.4-1.7)	6.7 (1.6-27)	2081.3	-1031.6	0.890 (0.869-0.908)
Observation-level random effects	3.9 (3.0-5.1)	1.9 (1.4-2.5)	4.4 (2.6-7.7)	0.81 (0.7-0.94)	1.4 (1.2-1.6)	6.6 (1.6-27)	1997.2	-988.6	0.890 (0.869-0.907)
Beta-binomial hierarchical	3.4†	2.0†	5.2†	0.78†	1.5†	6.9†	2082.8	-1041.9	0.896 (0.876-0.912)
Poisson	3.0 (2.6-3.6)	1.9 (1.6-2.3)	4.4 (3.2-6.1)	0.80 (0.73-0.89)	1.5 (1.4-1.6)	5.9 (1.5-23)	2061	-1021.5	0.934 (0.921-0.945)
Negative binomial	3.5 (2.7-4.5)	1.8 (1.4-2.3)	4.0 (2.4-6.5)	0.83 (0.72-0.95)	1.4 (1.2-1.6)	5.8 (1.5-23)	1999.5	-989.8	0.957 (0.949-0.964)

* Akaike's information criterion.

§ Leave-one-out cross-validation predictions and true observations correlation (Pearson's rho and 95% confidence interval).

† Profile confidence intervals non-convergent.

Table S4. Carriage rates by study and age group.

Paper (Sample size)	Age group	Number of individuals	Carriage prevalence	Significantly lower prevalence than peak prevalence (p-value less than 0.0005)
Barnes 2016	1-4 years	1575	4.7%	***
(n = 7479)	5-9 years	2766	6.7%	
	10-14 years*	1674	6.3%	
	15-19 years	490	**9.8%**	Peak
	20-24 years	332	8.4%	
	25-29 years	642	7.9%	
Burian 1974	Under 1 year	60	6.7%	
(n = 2569)	1-4 years	173	11.6%	
	5-9 years	1191	5.6%	
	10-14 years*	881	4.3%	
	15-19 years	136	5.9%	
	20-29 years	68	5.9%	
	30-39 years	38	5.3%	
	40-49 years	15	0%	
	Over 50 years	7	**14.3%**	Peak
Emele 1999	1-4 years	95	8.4%	
(n = 726)	**5-9 years**	270	**8.5%**	Peak
	10-14 years*	303	4.3%	
	15-19 years	58	1.7%	
Etienne 1973	0-14 years*	63	20.6%	
(n = 95)	**15 plus years**	32	**34.4%**	Peak
Forgor 2005	Under 1 year	6	16.7%	
(n = 299)	1-4 years	78	7.7%	
	5-9 years	44	15.9%	
	10-14 years*	37	29.7%	
	15-19 years	24	**37.5%**	Peak
	20-39 years	93	14.0%	
	40 plus years	17	5.9%	
Kristiansen 2011	1-4 years	4588	2.3%	***
(n = 20326)	5-9 years	5496	4.3%	
	10-14 years*	3732	**5.1%**	Peak
	15-19 years	2810	4.9%	
	20-24 years	2080	4.1%	
	25-29 years	1620	3.4%	
Kristiansen 2013	1-4 years	6258	4.4%	***
(n = 25520)	5-9 years	6987	8.7%	
	10-14 years*	4883	**8.9%**	Peak
	15-19 years	3159	6.3%	***
	20-24 years	2369	3.3%	***
	25-29 years	1864	2.7%	***

*Age group containing 12 years of age.

Table S4 (continued). Carriage rates by study and age group.

Paper	Age group	Number of individuals	Carriage prevalence	Significantly lower prevalence than peak prevalence (p-value less than 0.0005)
Kristiansen 2014	1-4 years	1221	5.2%	***
(n = 4964)	**5-9 years**	1438	**11.2%**	Peak
	10-14 years*	896	9.7%	
	15-19 years	565	8.0%	
	20-24 years	455	5.1%	***
	25-29 years	389	2.8%	***
Leimkugel 2007	Under 5	40	5.0%	
(n = 300)	5-9 years	43	7.0%	
	10-14 years*	45	4.4%	
	15-19 years	34	2.9%	
	20-29 years	27	**11.1%**	Peak
	30-39 years	31	3.2%	
	40-49 years	33	3.0%	
	50 plus years	47	2.1%	
MenAfriCar Consortium 2015	Under 1 year	2195	1.2%	***
(n = 48404)	1-4 years	8817	1.4%	***
	5-14 years*	13105	**2.7%**	Peak
	15-29 years	12407	1.9%	***
	30-44 years	6575	1.3%	***
	45 plus years	5305	1.5%	***
Mueller 2011	1 year	30	16.7%	
(n = 615)	2-4 years	124	9.7%	***
	5-9 years	156	25.6%	
	10-19 years*	154	24.0%	
	20-29 years	82	**31.7%**	Peak
	30-39 years	69	13.0%	
Trotter 2013	0-0.5 years	56	0%	
(n = 1037)	0.5-1 years	53	0%	
	1-4 years	120	0.8%	
	5-9 years	120	2.5%	
	10-14 years*	115	0%	
	15-19 years	118	0%	
	20-24 years	118	0.8%	
	25-29 years	115	2.6%	
	30-39 years	110	0.9%	
	40 plus years	112	**2.7%**	Peak
Yaro 2007	**4-14 years***	224	**4.5%**	Peak
(n = 456)	15-29 years	232	2.6%	

Table S5. Random effects intercepts for location term.

Location	Intercept
Bobo-Dioulasso, Burkina Faso	-0.14
Bogodogo, Burkina Faso	0.13
Dande, Burkina Faso	0.81
Kaya, Burkina Faso	1.16
Secteur 15, Burkina Faso	0.34
Mandelia, Chad	-0.8
N'Djamena, Chad	-0.59
Arba Minch, Ethiopia	0.4
Butajira (rural), Ethiopia	-0.02
Butajira (urban), Ethiopia	-0.31
Kassena-Nankana (town), Ghana	0.34
Kassena-Nankana District, Ghana	0.28
Kpalkpalgbeni, Brong-Ahafo, Ghana	0.28
Navrongo, Ghana	-0.32
Bamako, Mali	-0.11
Bamako and Koulikoro, Mali	0.26
Narena and Siby, Mali	-0.6
Niamey, Niger	0.53
Say, Niger	-0.05
Yantala, Niger	0.33
Konduga, Nigeria	-1.22
Maiduguri, Nigeria	-0.46
Malumfashi, Kaduna State, Nigeria	-0.58
Fatick, Senegal	0.25
Niakkar, Senegal	0.45
Fajikunda, The Gambia	0.19

Table S6. Random effects intercepts for location-year interaction term.

Location	Year												
	1970	1977	1978	1998	2003	2006	2008	2009	2010	2011	2012	2013	2014
Bobo-Dioulasso, Burkina Faso	...	...	...	...	0.34	...	-0.60	...	...	...	...	...	...
Bogodogo, Burkina Faso	...	...	...	...	...	...	...	-0.22	0.47	-0.36	0.35	...	...
Dande, Burkina Faso	...	...	...	...	...	...	...	-0.11	0.07	-0.25	1.81	...	...
Kaya, Burkina Faso	...	...	...	...	...	...	...	0.01	1.87	0.70	-0.40	...	...
Secteur 15, Burkina Faso	...	...	...	...	...	0.63	...	...	...	...	...	...	...
Mandelia, Chad	...	...	...	...	...	...	...	...	0.01	0.51	-2.01	...	...
N'Djamena, Chad	...	...	...	...	...	...	...	...	-0.18	-0.25	-0.67	...	...
Arba Minch, Ethiopia	...	...	...	...	...	...	...	...	...	...	...	...	0.75
Butajira (rural), Ethiopia	...	...	...	...	...	...	...	...	0.42	0.45	-0.90	...	...
Butajira (urban), Ethiopia	...	...	...	...	...	...	...	0.04	0.5	-0.23	-0.88	...	...
Kassena-Nankana, Ghana	...	...	...	...	...	...	...	...	-0.9	1.14	0.41	...	...
Kassena-Nankana District, Ghana	...	...	...	0.52	...	...	...	...	...	...	...	...	...
Kpalkpalgbeni, Brong-Ahafo, Ghana	...	...	...	...	0.52	...	...	...	...	...	...	...	...
Navrongo, Ghana	...	...	...	...	...	...	...	...	-1.49	-0.61	1.49	...	...
Bamako, Mali	...	...	...	...	...	...	...	1.74	-1.32	-0.02	-0.60	...	...
Bamako and Koulikoro, Mali	0.49	...	...	...	...	...	...	...	...	...	...	...	...
Narena and Siby, Mali	...	...	...	...	...	...	...	...	-0.94	-0.52	0.35	...	...
Niamey, Niger	...	...	...	...	1.00	...	...	...	...	...	...	...	...
Say, Niger	...	...	...	...	...	...	...	-0.19	-0.18	0.70	-0.42	...	...
Yantala, Niger	...	...	...	...	...	...	...	...	0.65	0.73	-0.76	...	...
Konduga, Nigeria	...	...	...	...	...	...	...	...	-1.08	-1.19	...	...	...
Maiduguri, Nigeria	...	...	...	...	...	...	...	...	-0.86	...	...	...	...
Malumfashi, Kaduna State, Nigeria	...	-0.20	-0.87	...	...	...	...	...	...	...	...	...	...
Fatick, Senegal	...	...	...	...	...	...	...	...	-0.33	-0.7	1.49	...	...
Niakkar, Senegal	...	...	...	...	...	...	...	-0.99	-0.27	-0.11	2.21	...	...
Fajikunda, The Gambia	...	...	...	...	...	...	...	...	...	...	...	0.35	...

Figure S2. Carriage prevalence by age (circles), median bootstrap predictions including random effects (line) and bias-corrected 95% confidence intervals (ribbon) by location and year. Dry season predictions shown in red; rainy season in blue; outbreak periods in green. Note the change in scale.
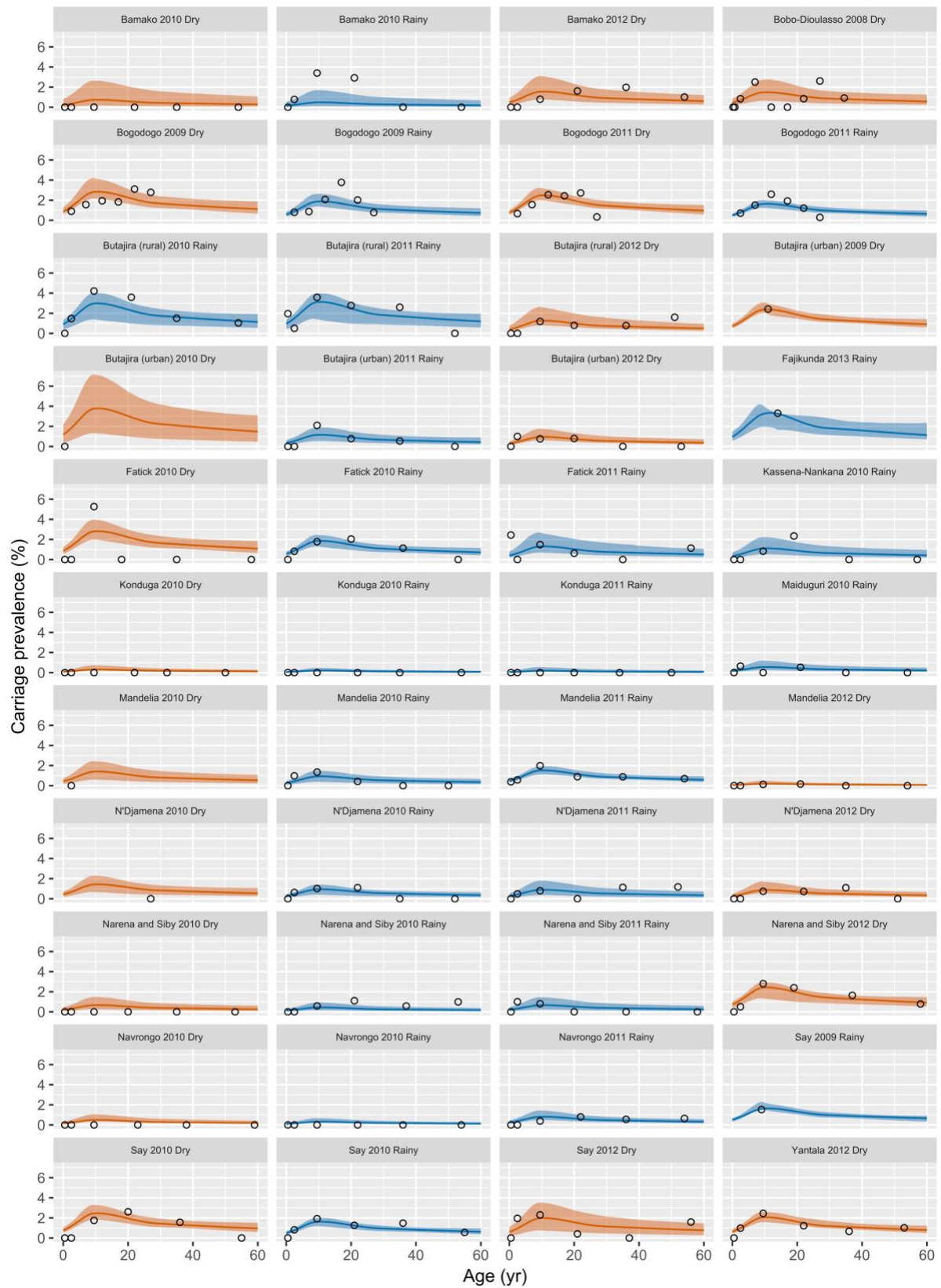
Figure S2 (ctd). Carriage prevalence by age (circles), median bootstrap predictions including random effects (line) and bias-corrected 95% confidence intervals (ribbon) by location and year. Dry season predictions shown in red; rainy season in blue; outbreak periods in green. Note the change in scale.
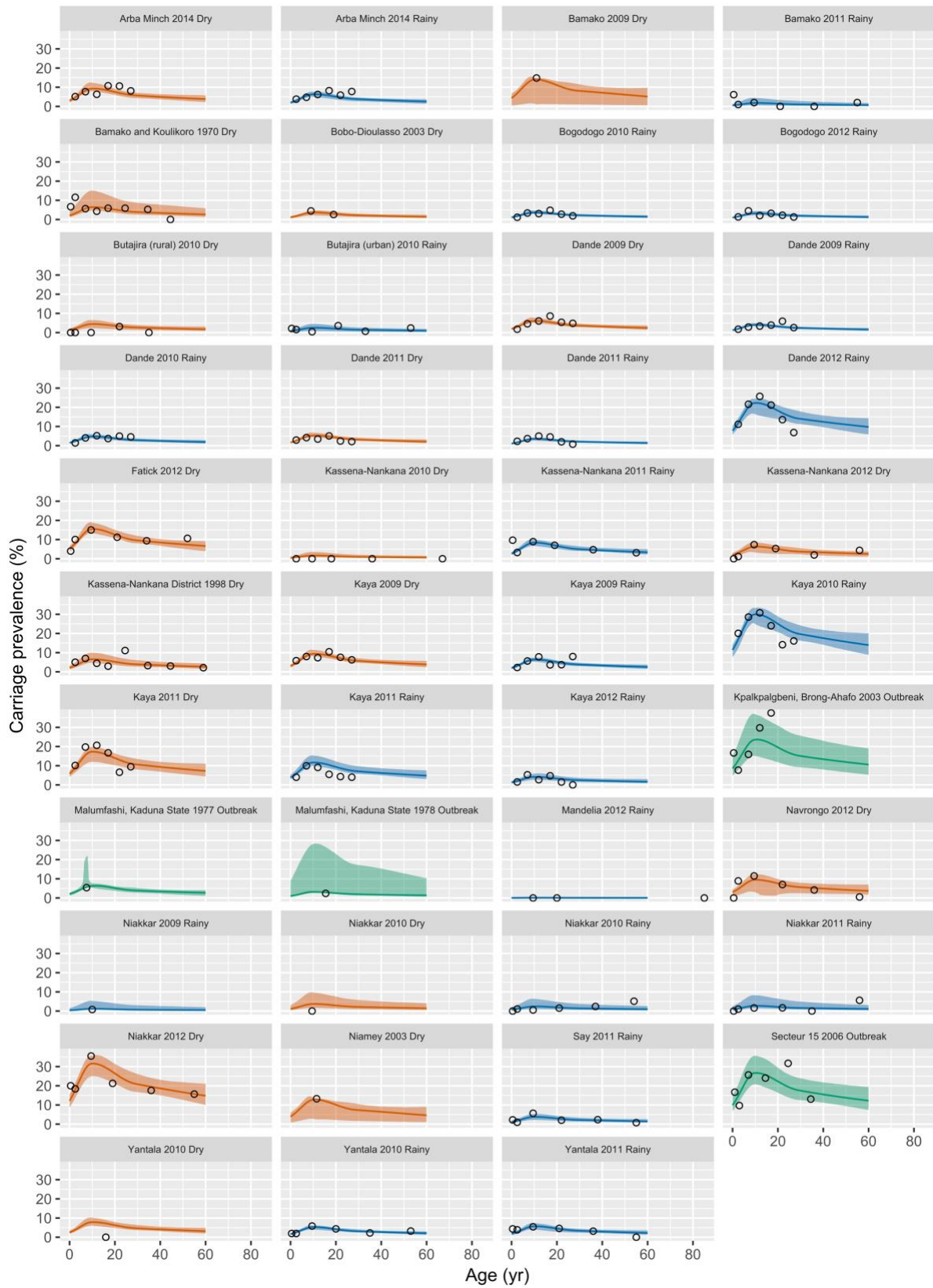
Figure S3. Comparison of model fit (fixed effects) on the full data set (pink and black points) and excluding climactic outliers (pink points only). Carriage prevalence by age (circles), median bootstrap predictions (line) and bias-corrected 95% confidence intervals (ribbon) by epidemiological category.