Supplementary Materials 1

Step 1) Exploratory q runs (*e.g.* q5+ is model run with q deviations fixed at zero for ages 6+). In all cases, one cv parm per survey, crl std fixed at 0.20, AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

q runs

q	np	nll	AIC	BIC
5+	40	4817	9713	9915
6+	43	4807	9700	9917
7+	46	4799	9690	9922
8+	49	4799	9696	9943
9+	52	4799	9702	9964
10+	55	4799	9708	9985
11+	58	4798	9713	10005
12+	61	4793	9708	10016
13+	64	4789	9706	10028
14+	67	4780	9695	10032

Step 2) For all runs, m_q's for ages 8+ fixed at zero (*i.e.* q_8+=q_7). For all runs below parentheses represent pooled ages and ,., represent separate ages (*e.g.* 1,.,3(4–12) 13,.,15 is sep. sd parm for ages 1,2,3, 13,14,15 and pooled for ages (4–12)). crl sd fixed at 0.20, AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

		Fall cv			Spring cv			Spanish cv		
Model	np	nll	AIC	BIC	nll	AIC	BIC	nll	AIC	BIC
(1–15)	46	4799	9690	9922	4799	9690	9922	4799	9690	9922
1(2–15)	47	4795	9683	9920	4777	9648	9885	4795	9684	9921
1,.,2(3–15)	48	4795	9685	9927	4768	9632	9874	4794	9684	9926
1,.,3(4–15)	49	4795	9687	9934	4768	9634	9881	4791	9681	9928
1,.,4(5–15)	50	4795	9689	9941	4767	9635	9887	4789	9678	9929
1,.,5(6–15)	51	4793	9687	9944	4767	9636	9893	4783	9669	9926
1,.,6(7–15)	52	4793	9689	9951	4765	9634	9896	4783	9670	9932
1,.,7(8–15)	53	4791	9687	9954	4765	9636	9903	4778	9662	9929
1,.,8(9–15)	54	4789	9685	9957	4764	9637	9909	4778	9664	9936
1,.,9(10–15)	55	4784	9677	9955	4763	9637	9914	4778	9666	9943
1,.,10(11–15)	56	4780	9671	9953	4760	9633	9915	4778	9668	9950
1,.,11(12–15)	57	4774	9661	9948	4760	9635	9922	4778	9669	9957
1,.,12(13–15)	58	4772	9659	9952	4759	9634	9926	4778	9671	9964
1,.,13(14–15)	59	4771	9660	9958	4753	9623	9921	4778	9673	9971
1,.,15	60	4771	9662	9964	4753	9625	9928	4775	9670	9972
(1–15)	46	4799	9690	9922	4799	9690	9922	4799	9690	9922
(1–14)15	47	4799	9691	9928	4798	9691	9928	4799	9692	9929
(1–13)12,.,15	48	4797	9689	9931	4793	9682	9924	4797	9689	9931
(1–13)12,.,15	49	4786	9669	9916	4793	9683	9930	4794	9686	9933
(1–13)12,.,15	50	4783	9666	9917	4791	9681	9933	4793	9686	9938
(1–13)12,.,15	51	4783	9667	9924	4791	9683	9940	4790	9683	9940
(1–13)12,.,15	52	4782	9668	9930	4786	9677	9939	4788	9680	9942
(1–13)12,.,15	53	4780	9667	9934	4783	9673	9940	4785	9677	9944
(1–13)12,.,15	54	4780	9667	9939	4781	9669	9941	4781	9669	9941
(1–13)12,.,15	55	4777	9664	9942	4774	9658	9935	4780	9670	9947
(1–13)12,.,15	56	4777	9666	9948	4773	9657	9940	4777	9665	9947
(1–13)12,.,15	57	4775	9664	9951	4772	9659	9946	4776	9667	9954
(1–13)12,.,15	58	4775	9666	9958	4768	9652	9944	4776	9668	9960
(1–13)12,.,15	59	4774	9666	9963	4758	9634	9931	4776	9670	9967
(1–13)12,.,15	60	4771	9662	9964	4753	9625	9928	4775	9670	9972

Step 2 cont'd) Fall exploratory runs. For all runs, m_q's for ages 8+ fixed at zero (*i.e.* q_8+=q_7). For all runs below parentheses represent pooled CV ages and **,.,** represent separate CV ages (*e.g.* 1,.,3(4–12) 13,.,15 is sep. CV parm for ages 1,2,3, 13,14,15 and pooled for ages (4–12)). crl sd fixed at 0.20, AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

Fall 1

Model	np	nll	AIC	BIC
(1–12)13,.,15	49	4786	9669	9916
1,(2–12)13,.,15	50	4779	9658	9910
1,,2(3–12) 13,.,15	51	4779	9660	9917
1,,3(4–12) 13,.,15	52	4779	9662	9924
1,,4(5–12) 13,.,15	53	4779	9663	9930
1,,5(6–12) 13,.,15	54	4778	9664	9936
1,,6(7–12) 13,.,15	55	4777	9664	9941
1,,7(8–12) 13,.,15	56	4776	9665	9947
1,,8(9–12) 13,.,15	57	4776	9666	9954
1,,9(10–12) 13,.,15	58	4775	9665	9957
1,,10(11–12) 13,.,15	59	4773	9665	9962
1,.,15	49	4786	9669	9916

Fall 2

Model	np	nll	AIC	BIC
1,(2-3)(4-12)(13-15)	49	4780	9658	9905
1,(2-4)(5-12)(13-15)	49	4779	9657	9904
1,(2-5)(6-12)(13-15)	49	4780	9658	9905
1,(2-6)(7-12)(13-15)	49	4779	9657	9904
1,(2-7)(8-12)(13-15)	49	4780	9658	9905
1,(2-8)(9-12)(13-15)	49	4780	9658	9905
1,(2-9)(10-12)(13-15)	49	4780	9657	9904
1,(2-10)(11-12)(13-15)	49	4779	9655	9902
1,(2-11)(12)(13-15)	49	4776	9651	9898
1,(2–12)(13–15)	48	4780	9656	9898

Fall 3

Model	np	nll	AIC	BIC
1,(2–3)(4–11)(12–15)	49	4778	9654	9901
1,(2–4)(5–11)(12–15)	49	4777	9652	9899
1,(2–5)(6–11)(12–15)	49	4778	9654	9901
1,(2–6)(7–11)(12–15)	49	4776	9650	9897
1,(2–7)(8–11)(12–15)	49	4777	9653	9900
1,(2–8)(9–11)(12–15)	49	4778	9653	9900
1,(2–9)(10–11)(12–15)	49	4778	9654	9901
1,(2–10)(11)(12–15)	49	4778	9654	9901
1,(2–11)(12–15)	48	4778	9652	9894

Fall 4

Model		nll	AIC	BIC
1,(2–6)(7–8)(9–11)	50	4776	9652	9904
1,(2–6)(7–9)(10–11)	50	4776	9651	9903
1,(2–6)(7–10)(11)	50	4776	9651	9903

Step 2 cont'd) Spring exploratory runs. For all runs, m_q's for ages 8+ fixed at zero (*i.e.* q_8+=q_7). For all runs below parentheses represent pooled ages and ,., represent separate ages (*e.g.* 1,.,3(4–12) 13,.,15 is sep. CV parm for ages 1,2,3, 13,14,15 and pooled for ages (4–12)). crl sd fixed at 0.20, AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

Spring 1

Model	np	nll	AIC	BIC
1,.,2(3–15)	48	4768	9632	9874
1,.,2(3–14)15	49	4767	9633	9880
1,.,2(3–13)14,.,15	50	4760	9620	9872
1,.,2(3–12)13,.,15	51	4760	9622	9879
1,.,2(3–11)12,.,15	52	4760	9623	9885
1,.,2(3–10)11,.,15	53	4759	9624	9891
1,.,2(3–9)10,.,15	54	4758	9625	9897
1,.,2(3–8)9,.,15	55	4757	9625	9902
1,.,2(3–7)8,.,15	56	4756	9624	9906
1,.,2(3–6)7,.,15	57	4754	9623	9910
1,.,2(3–5)6,.,15	58	4754	9624	9917
1,.,2(3–4)5,.,15	59	4753	9623	9921
1,.,15	60	4753	9625	9928

Spring 2

Model	np	nll	AIC	BIC
1,.,2(3-4)(5-13)(14-15)	50	4760	9620	9872
1,.,2(3–5)(6–13)(14–15)	50	4760	9620	9871
1,.,2(3–6)(7–13)(14–15)	50	4757	9614	9866
1,.,2(3–7)(8–13)(14–15)	50	4758	9616	9868
1,.,2(3–8)(9–13)(14–15)	50	4759	9618	9870
1,.,2(3–9)(10–13)(14–15)	50	4760	9619	9871
1,.,2(3–10)(11–13)(14–15)	50	4760	9619	9871
1,.,2(3–11)(12–13)(14–15)	50	4760	9620	9872
1,.,2(3–12)(13)(14–15)	50	4760	9620	9872
1,.,2(3–13)(14–15)	49	4760	9618	9865

Spring 3

Model	np	nll	AIC	BIC
1,.,2(3–4)(5–7)(8–13)(14–15)	51	4757	9617	9874
1,.,2(3–5)(6–7)(8–13)(14–15)	51	4758	9618	9875
1,.,2(3–6)(7)(8–13)(14–15)	51	4757	9616	9873

Spring 4

Model	np	nll	AIC	BIC
1,.,2(3–7)(8–9)(10–13)(14–15)	51	4758	9618	9875
1,.,2(3–7)(8–10)(11–13)(14–15)	51	4756	9615	9872
1,.,2(3–7)(8–11)(12–13)(14–15)	51	4758	9618	9875
1,.,2(3–7)(8–12)(13)(14–15)	51	4758	9618	9875

Step 2) cont'd) Spanish exploratory runs. For all runs, m_q's for ages 8+ fixed at zero (*i.e.* q_8+=q_7). For all runs below parentheses represent pooled ages and ,., represent separate ages (*e.g.* 1,.,3(4–12) 13,.,15 is sep. CV parm for ages 1,2,3, 13,14,15 and pooled for ages (4-12)). crl sd fixed at 0.20, AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

Spanish 1

Model	np	nll	AIC	BIC
1,(2–15)	47	4795	9684	9921
1,(2–14)15	48	4795	9686	9928
1,(2–13)14,.,15	49	4792	9683	9929
1,(2–12)13,.,15	50	4790	9680	9932
1,(2–11)12,.,15	51	4789	9681	9938
1,(2–10)11,.,15	52	4787	9678	9940
1,(2–9)10,.,15	53	4785	9676	9943
1,(2–8)9,.,15	54	4782	9673	9945
1,(2–7)8,.,15	55	4778	9666	9943
1,(2–6)7,.,15	56	4778	9668	9950
1,(2–5)6,.,15	57	4775	9664	9952
1,(2–4)5,.,15	58	4775	9666	9958
1,(2–3)4,.,15	59	4775	9668	9965

Spanish 2

Model	np	nll	AIC	BIC
1,(2–5)(6)(7–15)	49	4783	9665	9912
1,(2–5)(6–7)(8–15)	49	4779	9655	9902
1,(2–5)(6–8)(9–15)	49	4781	9659	9906
1,(2–5)(6–9)(10–15)	49	4782	9661	9908
1,(2–5)(6–10)(11–15)	49	4782	9662	9909
1,(2–5)(6–11)(12–15)	49	4783	9665	9912
1,(2–5)(6–12)(13–15)	49	4783	9665	9912
1,(2–5)(6–13)(14–15)	49	4784	9665	9912
1,(2–5)(6–14)(15)	49	4783	9665	9911
1,(2–5)(6–15)	48	4784	9664	9906

Spanish 3

Model	np	nll	AIC	BIC
1,(2–5)(6–7)(8)(9–15)	50	4778	9657	9909
1,(2–5)(6–7)(8–9)(10–15)	49	4784	9665	9912
1,(2–5)(6–7)(8–10)(11–15)	49	4782	9662	9909
1,(2–3)(6–7)(8–11)(12–15)	50	4779	9657	9909
1,(2–3)(6–7)(8–12)(13–15)	50	4779	9657	9909
1,(2–3)(6–7)(8–13)(14–15)	50	4779	9657	9909
1,(2–3)(6–7)(8–14)(15)	50	4777	9654	9906

Spanish 4

Model	np	nll	AIC	BIC
1,(2–7)(8–15)	48	4782	9659	9901

Step 3) Check qs with new survey cvs; Fall grouped 1(2-11)(12–15); Spring grouped 1,2,(3–13)(14–15); Spanish grouped 1(2-7)(8-15). In all cases, crl sd fixed at 0.20, AR1 age for all surveys fixed at 0.90. crl sd fixed at 0.20, AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

q runs

q	np	nll	AIC	BIC
5+	40	4817	9713	9915
6+	43	4807	9700	9917
7+	46	4799	9690	9922
8+	49	4799	9696	9943
9+	52	4799	9702	9964
10+	55	4799	9708	9985
11+	58	4798	9713	10005
12+	61	4793	9708	10016
13+	64	4789	9706	10028
14+	67	4780	9695	10032

q runs 2

q	np	nll	AIC	BIC
5+	47	4753	9599	9836
6+	50	4736	9571	9823
7+	53	4718	9543	9810
8+	56	4718	9548	9831
9+	59	4718	9554	9851
10+	62	4718	9560	9872
11+	65	4718	9565	9893
12+	68	4715	9567	9909
13+	71	4713	9567	9925
14+	74	4707	9562	9935

Step 4) crl exploratory runs. For all runs, m_q's for ages 8+ fixed at zero (*i.e.* q_8+=q_7), Fall grouped 1(2-11)(12-15); Spring grouped 1,2,(3–13)(14–15); Spanish grouped 1(2–7)(8–15). AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is number of parameters For all runs below parentheses represent pooled ages and ,., represent separate ages (*e.g.* 1,.,3(4–12) 13,.,15 is sep. CV parm for ages1,2,3,13,14,15 and pooled for ages (4–12)). np is the number of parameters, nll is the negative loglikelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

Crl PA					Crl 1					Crl 3				
Model	np	nll	AIC	BIC	**Model**	np	nll	AIC	BIC	**Model**	np	nll	AIC	BIC
(5–14)	54	4611	9331	9603	**5,.,6(7–14)**	56	4592	9295	9577	**(5–6)(7–8) (9–14)**	56	4594	9299	9581
5,(6–14)	55	4608	9327	9604	**5,.,6(7–13)14**	57	4590	9294	9582	**(5–6)(7–9) (10–14)**	56	4593	9298	9580
5,.,6(7–14)	56	4592	9295	9577	**5,.,6(7–12)13,.,14**	58	4590	9296	9589	**(5–6)(7–10) (11–14)**	56	4593	9297	9579
5,.,7(8–14)	57	4589	9293	9580	**5,.,6(7–11)12,.,14**	59	4584	9286	9583	**(5–6)(7–11) (12–14)**	56	4590	9291	9573
5,.,8(9–14)	58	4588	9292	9585	**5,.,6(7–10)11,.,14**	60	4584	9288	9590	**5–6)(7–12) (13–14)**	56	4593	9299	9581
5,.,9(10–14)	59	4586	9291	9588	**5,.,6(7–9)10,.,14**	61	4584	9290	9597	**(5–6)(7–13) (14)**	56	4592	9296	9578
5,.,10(11–14)	60	4585	9291	9593	**5,.,6(7–8)10,.,14**	62	4584	9291	9604	**(5–6)(7–14)**	55	4594	9297	9574
5,.,11(12–14)	61	4582	9286	9593										
5,.,12(13–14)	62	4580	9285	9597										
5,.,14	63	4579	9283	9601										
Crl PD					**Crl 2**									
(5–13)14	55	4609	9329	9606	**5,.,6(7–8)(9–14)**	57	4592	9297	9584					
(5–12)13,,14	56	4609	9330	9612	**5,.,6(7–9)(10–14)**	57	4591	9296	9583					
(5–11)12,,14	57	4607	9327	9615	**5,.,6(7–10)(11–14)**	57	4591	9295	9582					
(5–10)11,,14	58	4606	9328	9620	**5,.,6(7–11)(12–14)**	57	4587	9289	9576					
(5–9)10,.,14	59	4604	9326	9624	**5,.,6(7–12)(13–14)**	57	4591	9297	9584					
(5–8)9,.,14	60	4601	9322	9624	**5,.,6(7–13)(14)**	57	4590	9294	9582					
(5–7)8,.,14	61	4591	9304	9611										
(5–6)7,.,14	62	4580	9285	9597										
5,.,14	63	4579	9283	9601										

Step 5a/b) crl exploratory runs by year. For all runs, m_q's for ages 8+ fixed at zero (*i.e.* q_8+=q_7), Fall grouped 1(2–11)(12–15); Spring grouped 1,2,(3–7)(8–13)(14–15); Spanish grouped 1(2–7)(8–15). AR1 crl age/year fixed at 0.9/0, AR1 F fixed at 0.90. np is number of parameters. crl ages grouped (5-6)(7-11)(12-14). np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

Crl 1 split

Model	np	nll	AIC	BIC
PA90	59	4572	9262	9559
PA91	59	4573	9264	9561
PA92	59	4573	9264	9561
PA93	59	4571	9260	9557
PA94	59	4573	9264	9561
PA95	59	4583	9285	9582
PA96	59	4579	9276	9573
PA97	59	4568	9253	9550
PA98	59	4568	9255	9552
PA99	59	4568	9253	9550
Crl 2 block				
P90	57	4540	9194	9481
P91	57	4552	9218	9505
P92	57	4556	9227	9514
P93	57	4559	9232	9520
P94	57	4560	9235	9522
P95	57	4565	9243	9531
P96	57	4593	9300	9587
P97	57	4594	9303	9590
P98	57	4587	9288	9575
P99	57	4583	9280	9568

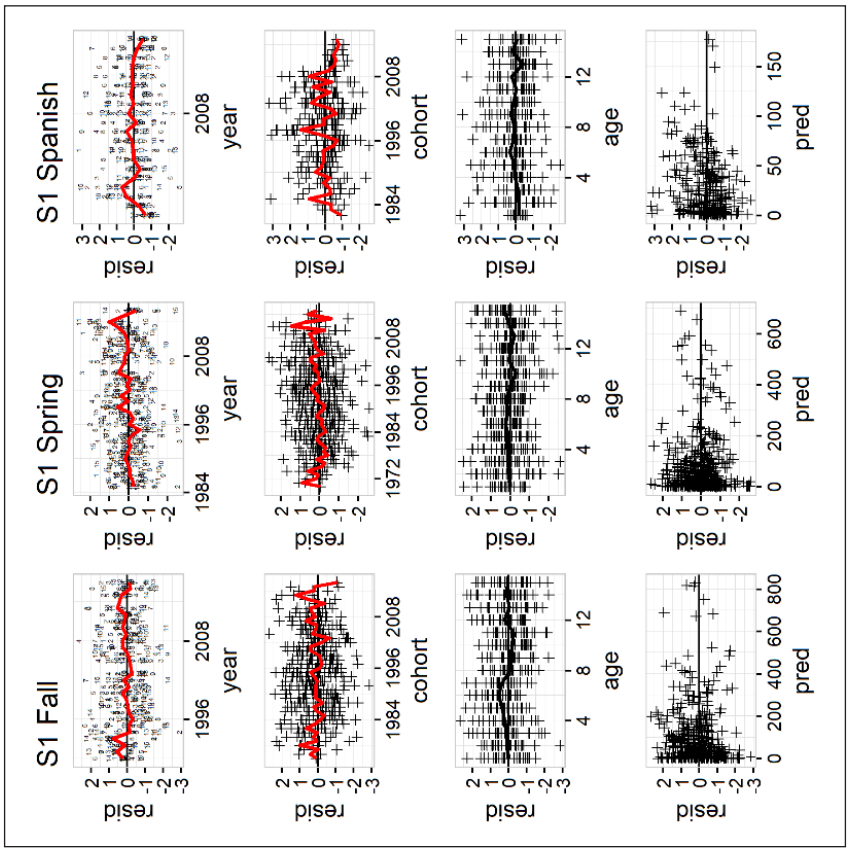
Step 6) Check qs with new crl sds; crl ages are pooled for ages (5–6)(7–11)(12–14), with a sep sd parm pre/post 1993; Fall grouped 1(2–11)(12–15); Spring grouped 1,2,(3–13)(14–15); Spanish grouped 1(2-7)(8–15) AR1 crl age/year fixed at 0.9/0, AR1F fixed at 0.90. np is the number of parameters, nll is the negative log-likelihood, AIC is the Akaike information criterion and BIC is the Bayesian information criterion.

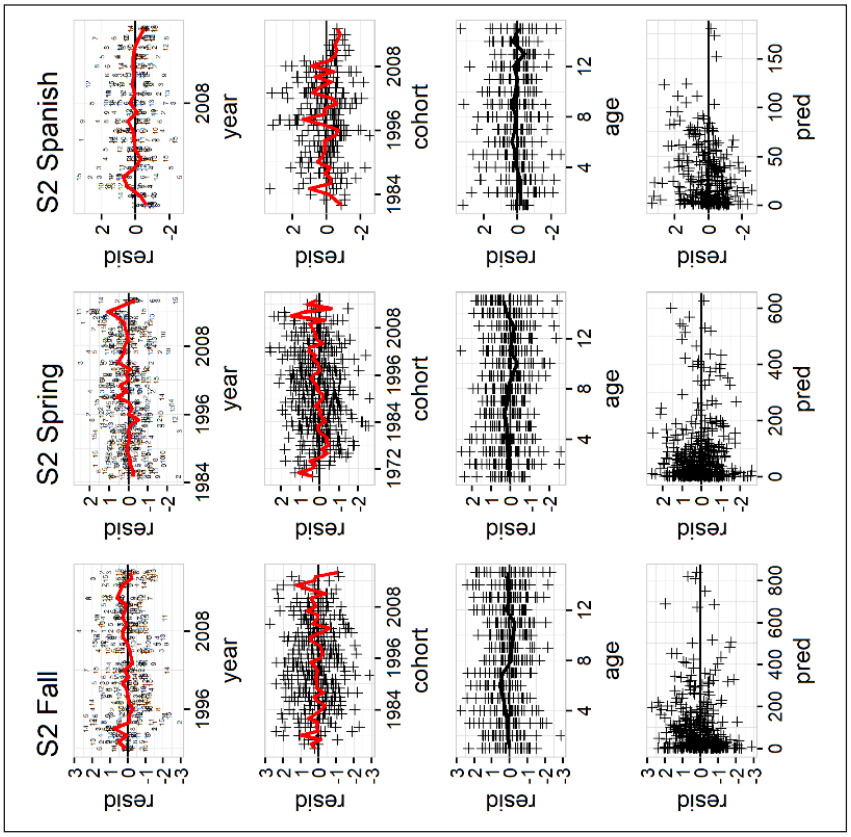
q runs					**q runs 2**					**q runs 3**				
q	np	nll	AIC	BIC	**q**	np	nll	AIC	BIC	**q**	np	nll	AIC	BIC
5+	40	4817	9713	9915	**5+**	47	4753	9599	9836	**5+**	51	4572	9246	9503
6+	43	4807	9700	9917	**6+**	50	4736	9571	9823	**6+**	54	4553	9213	9485
7+	46	4799	9690	9922	**7+**	53	4718	9543	9810	**7+**	57	4540	9194	9481
8+	49	4799	9696	9943	**8+**	56	4718	9548	9831	**8+**	60	4540	9199	9502
9+	52	4799	9702	9964	**9+**	59	4718	9554	9851	**9+**	63	4539	9205	9522
10+	55	4799	9708	9985	**10+**	62	4718	9560	9872	**10+**	66	4539	9211	9543
11+	58	4798	9713	10005	**11+**	65	4718	9565	9893	**11+**	69	4539	9216	9564
12+	61	4793	9708	10016	**12+**	68	4715	9567	9909	**12+**	72	4539	9221	9584
13+	64	4789	9706	10028	**13+**	71	4713	9567	9925	**13+**	75	4539	9227	9605
14+	67	4780	9695	10032	**14+**	74	4707	9562	9935	**14+**	78	4535	9227	9620

Supplementary Materials 2

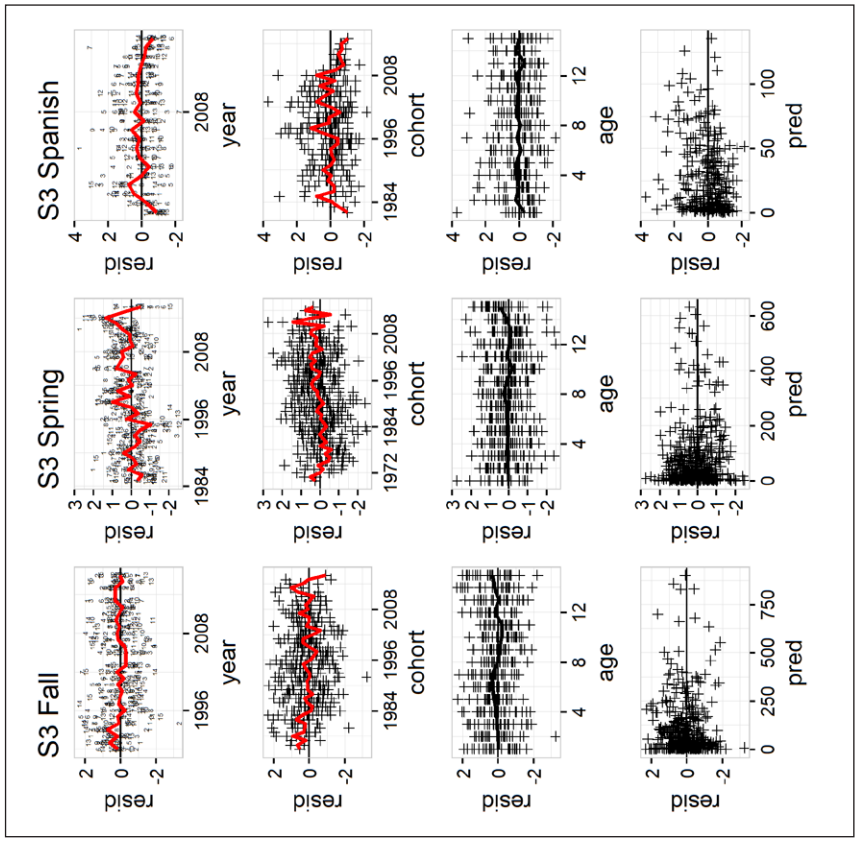
SSM Exploratory model fits; best model formulation

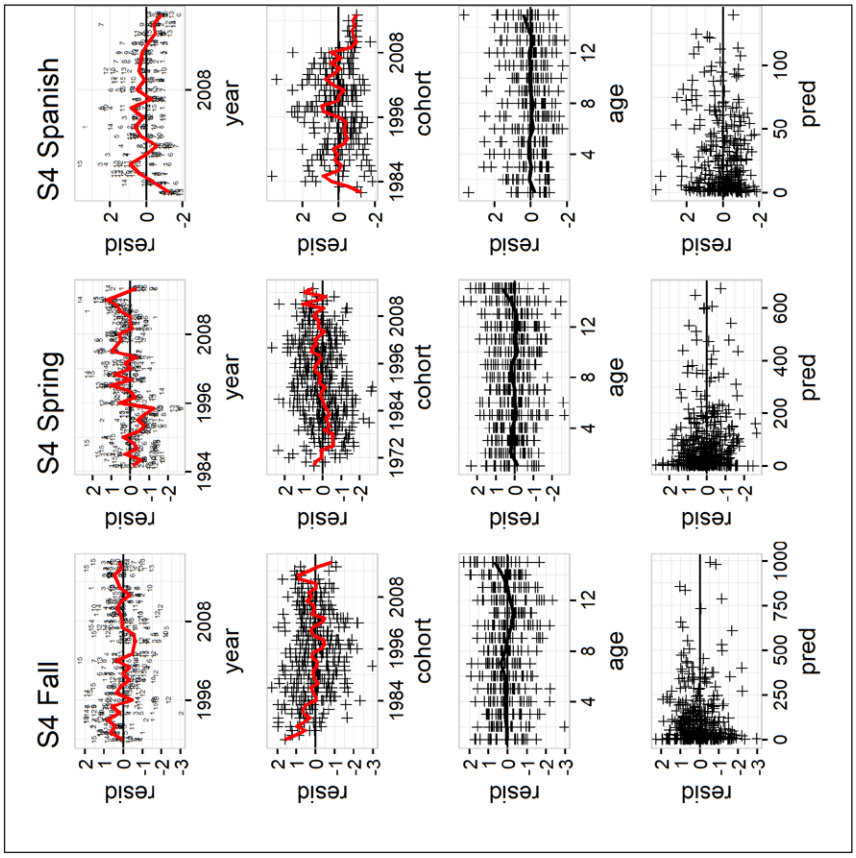
Survey index residuals





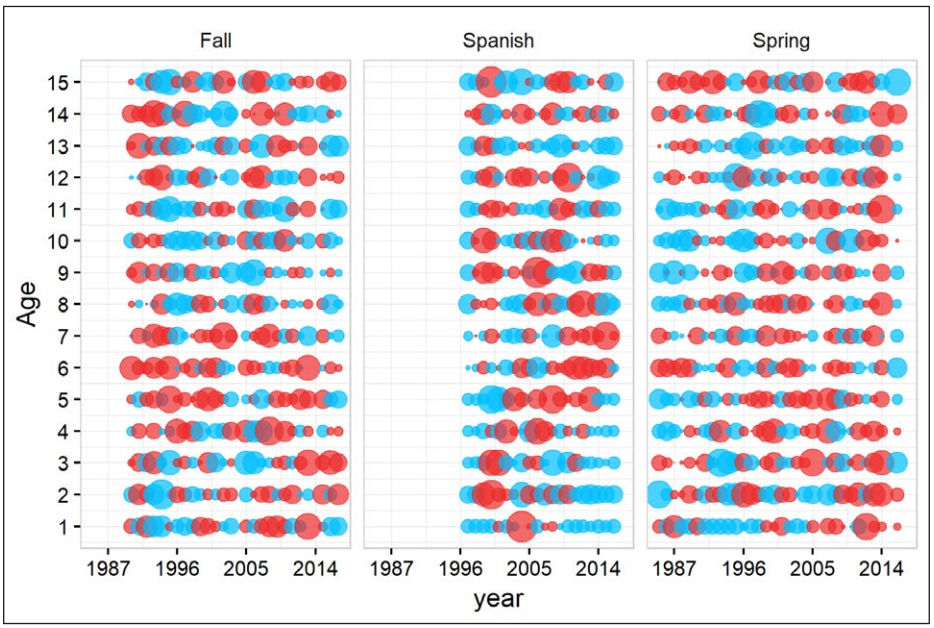
Survey index residuals



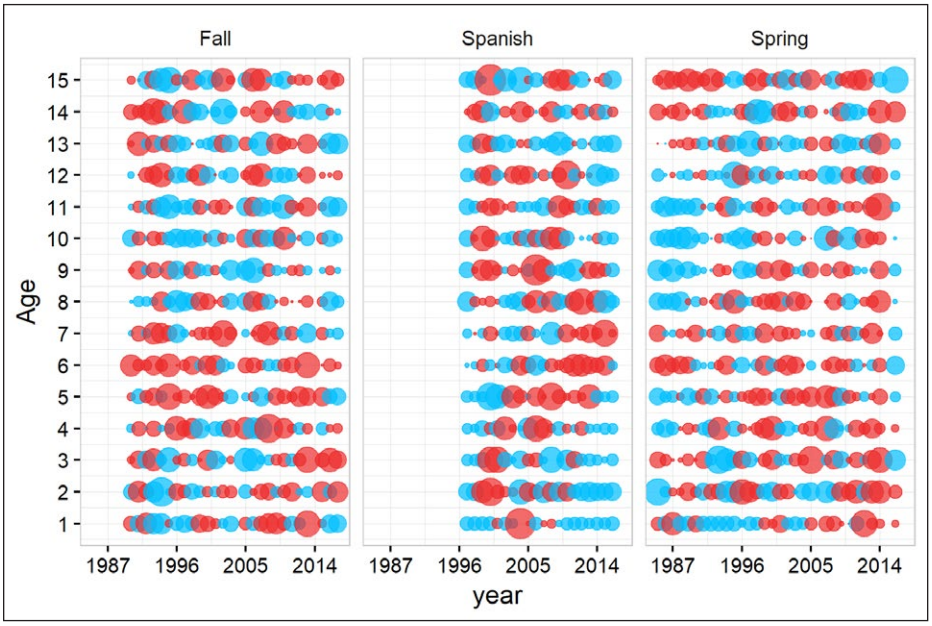


Survey index bubble plots

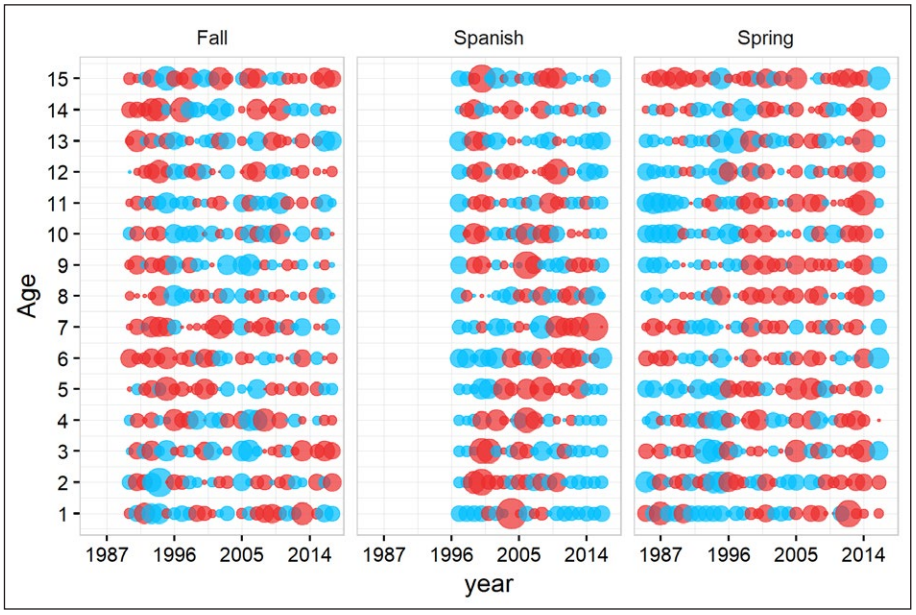
S1



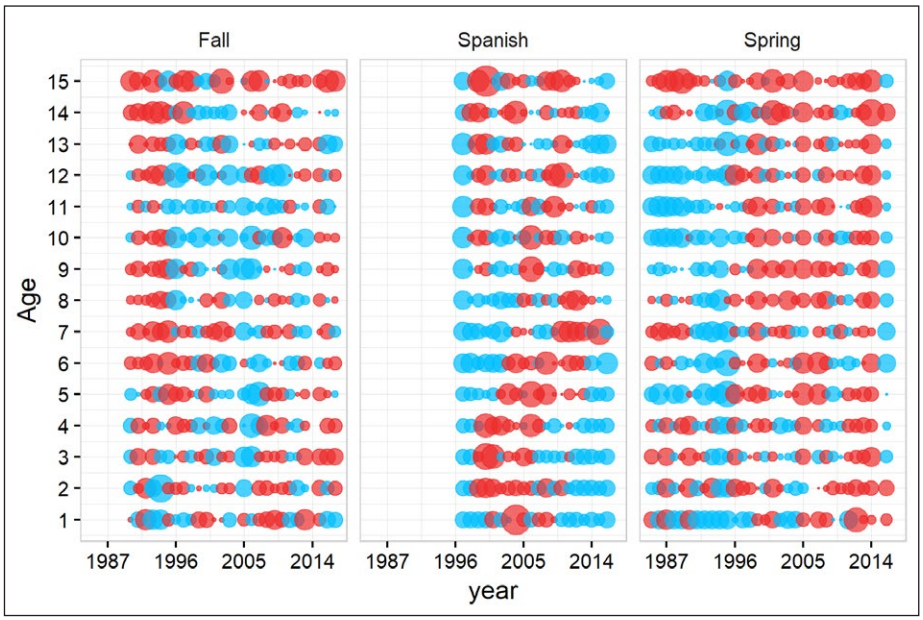
S2



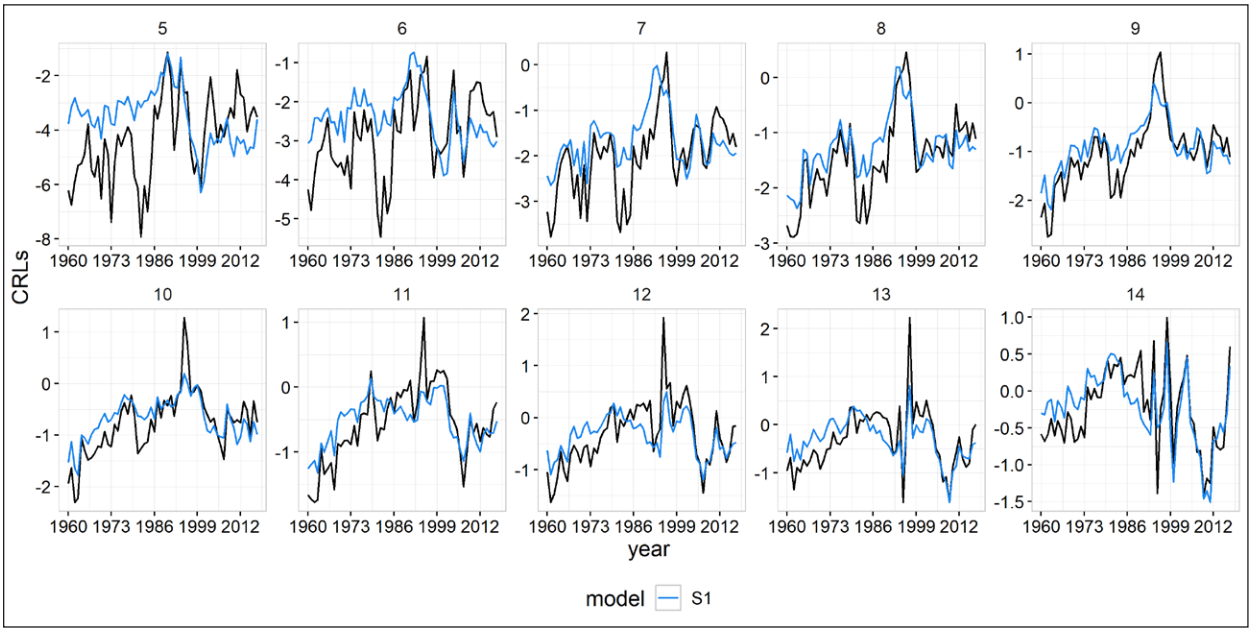
S3

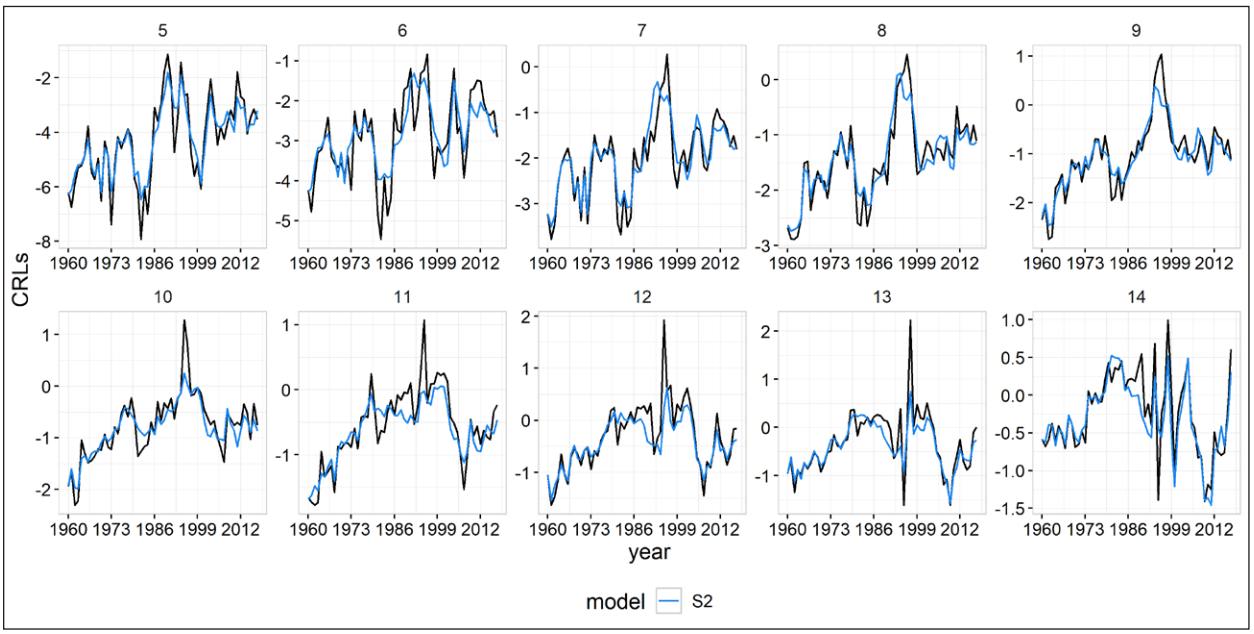

Fall
Spanish
Spring
Age
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1987
1996
2005
2014
year

S4

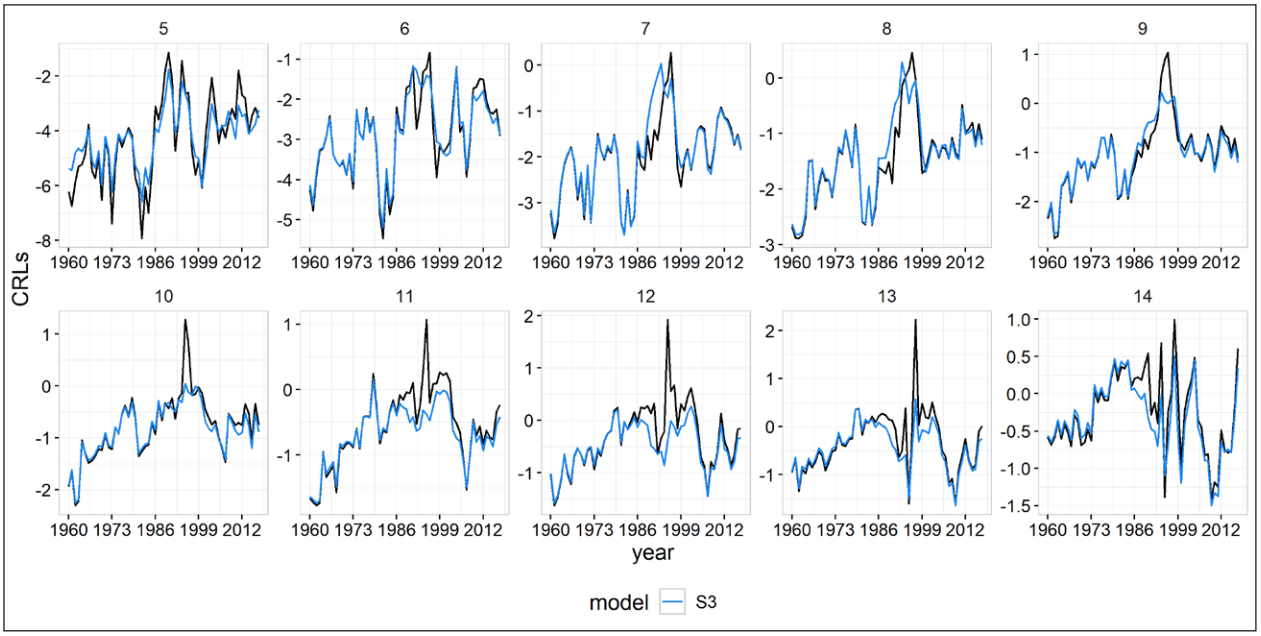

Fall
Spanish
Spring
Age
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1987
1996
2005
2014
year

Crl fits


5
6
7
8
9
10
11
12
13
14
CRLs
year
1960 1973 1986 1999 2012
model S1


5
6
7
8
9
10
11
12
13
14
CRLs
year
1960 1973 1986 1999 2012
model S2

Crl fits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6
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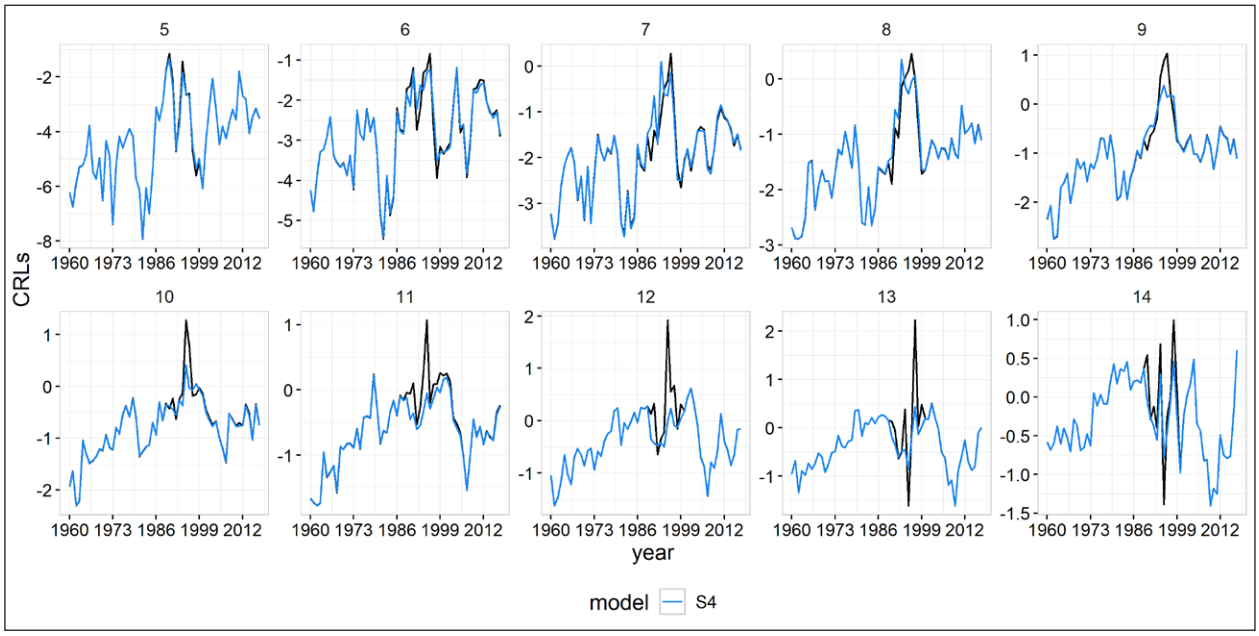
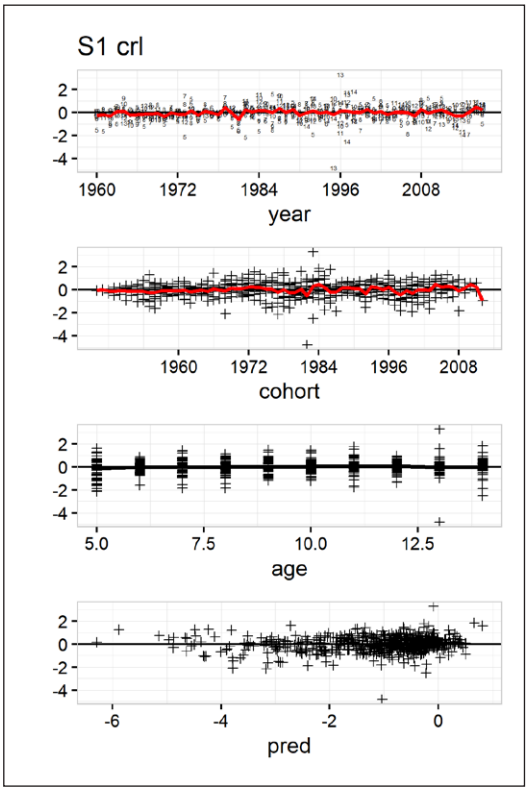
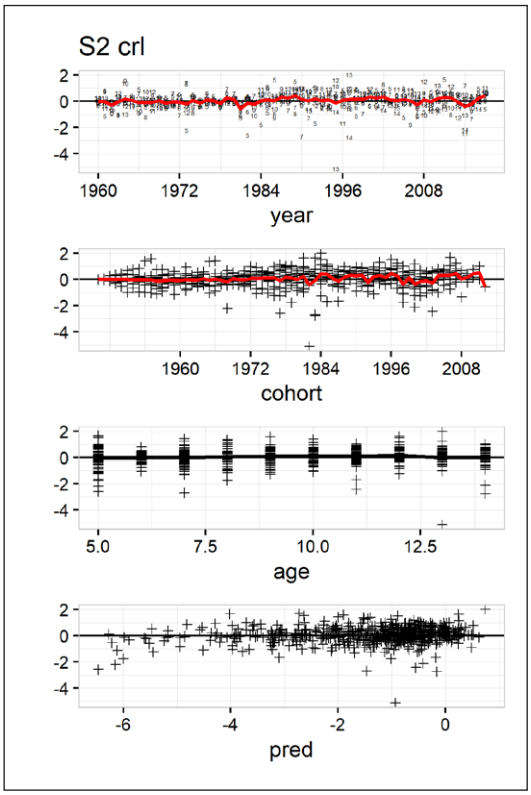
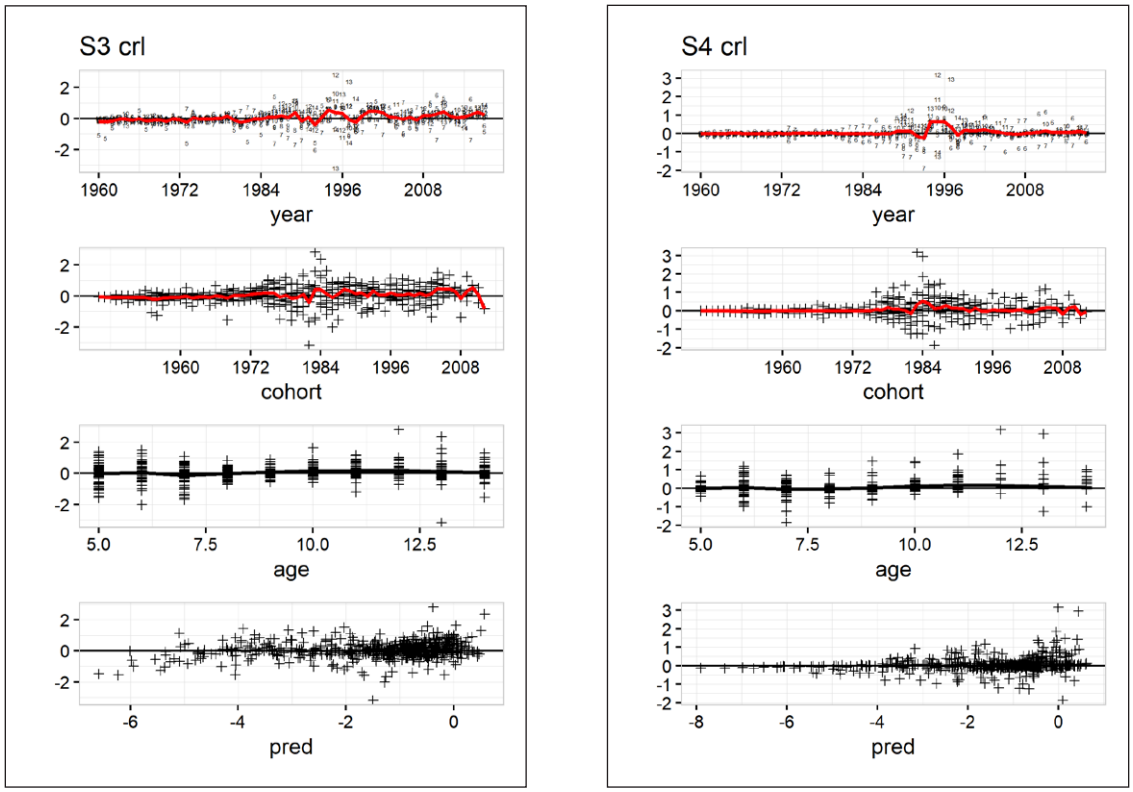
9
10
11
12
13
14
CRLs
year
1960 1973 1986 1999 2012
model
S3


5
6
7
8
9
10
11
12
13
14
CRLs
year
1960 1973 1986 1999 2012
model
S4

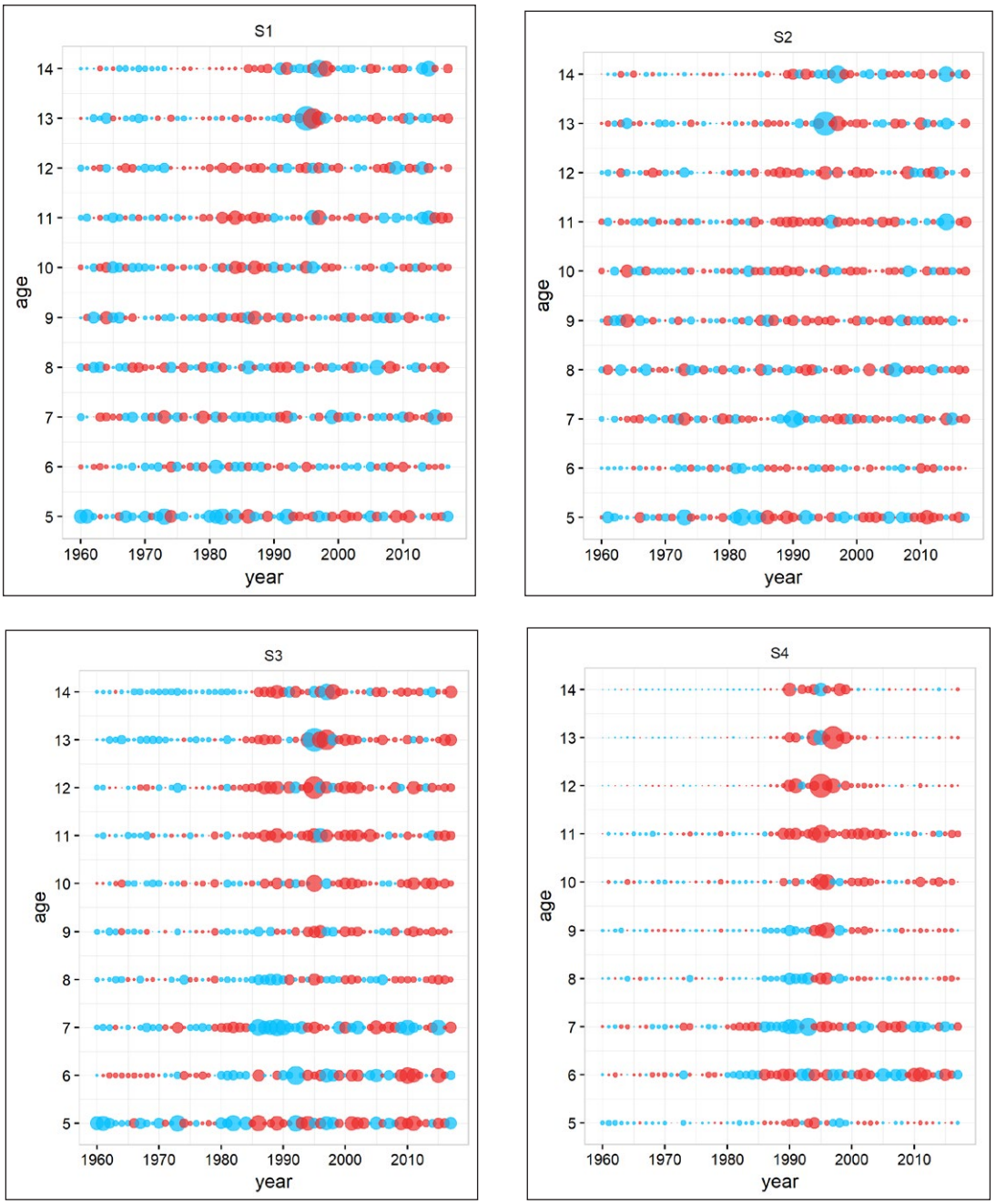
Crl residuals






S3 crl
year
cohort
age
pred
S4 crl
year
cohort
age
pred

Crl bubble plot residuals



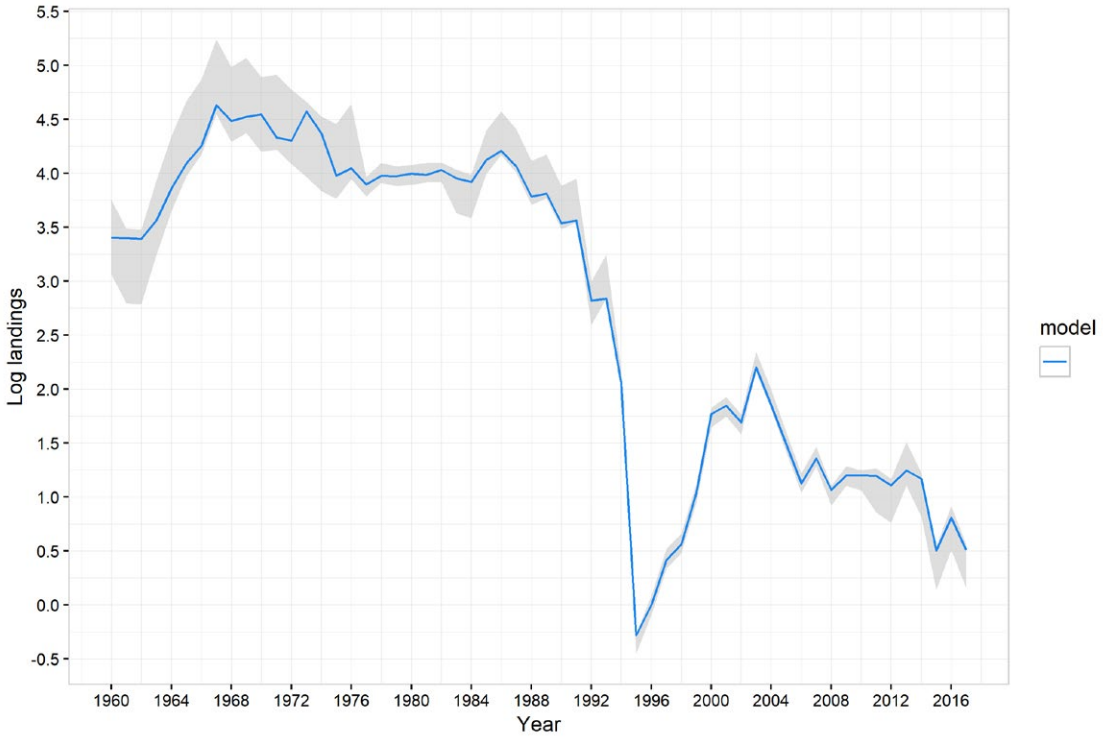
Supplementary Materials 3

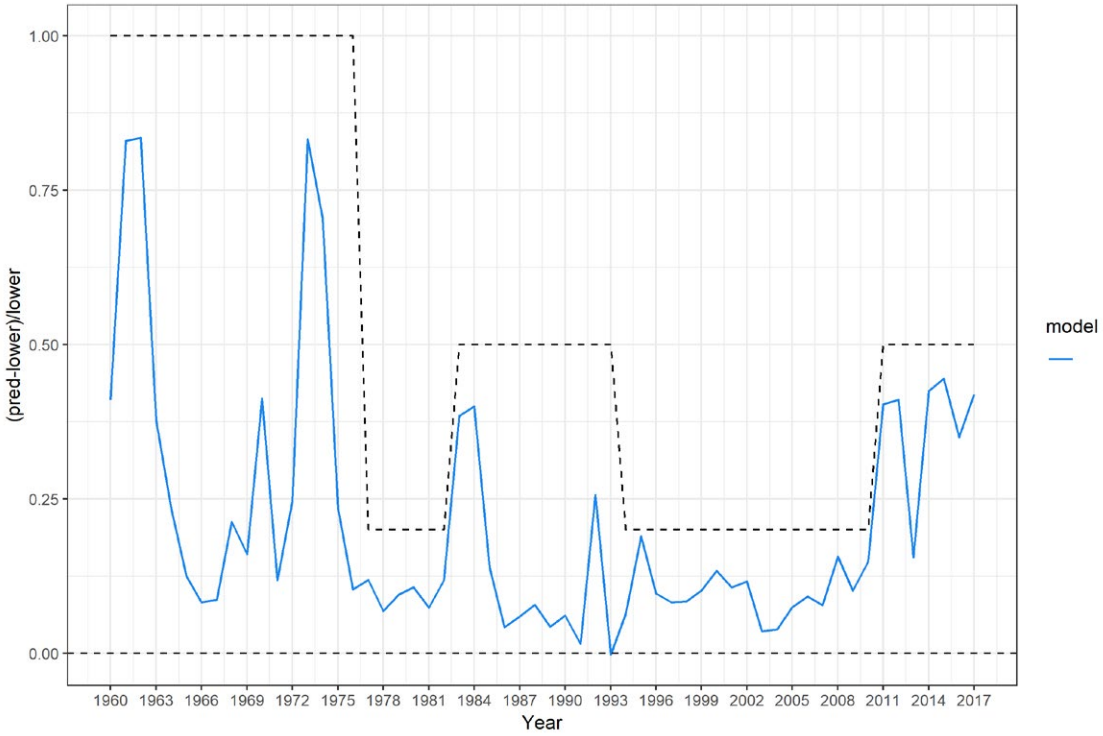
Final model fit

Model fit

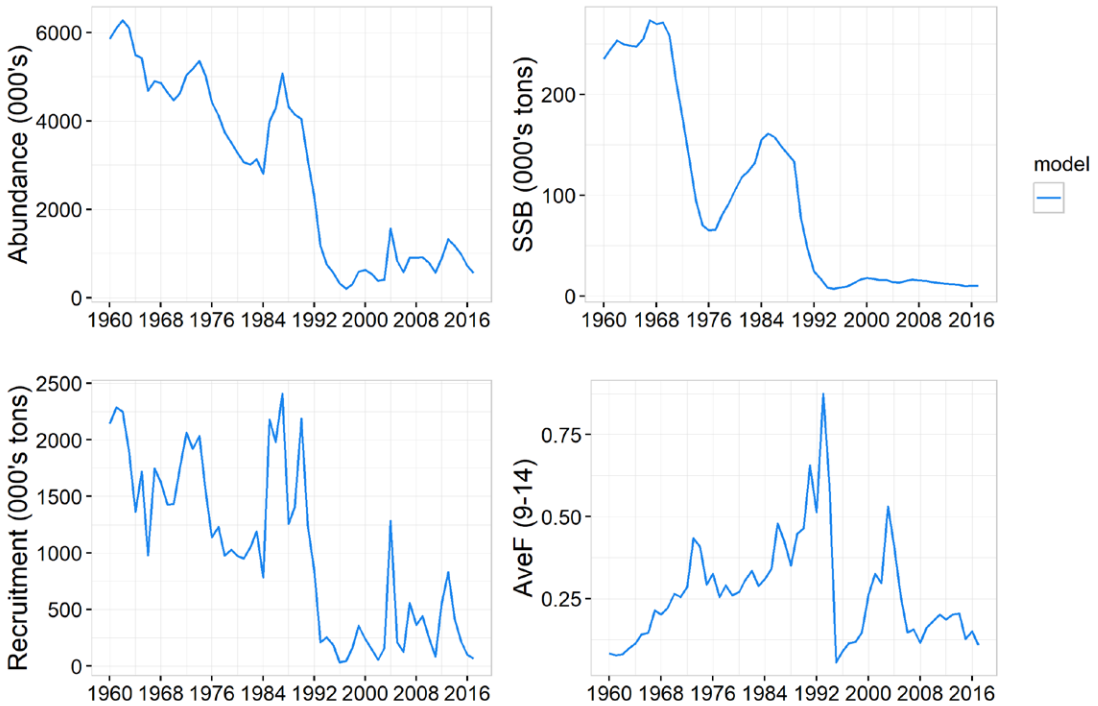
Model	nparms	nll	AIC	BIC	conv	maxabs gr
	60	4524	9168	9470	rel	0.000

Estimated landings



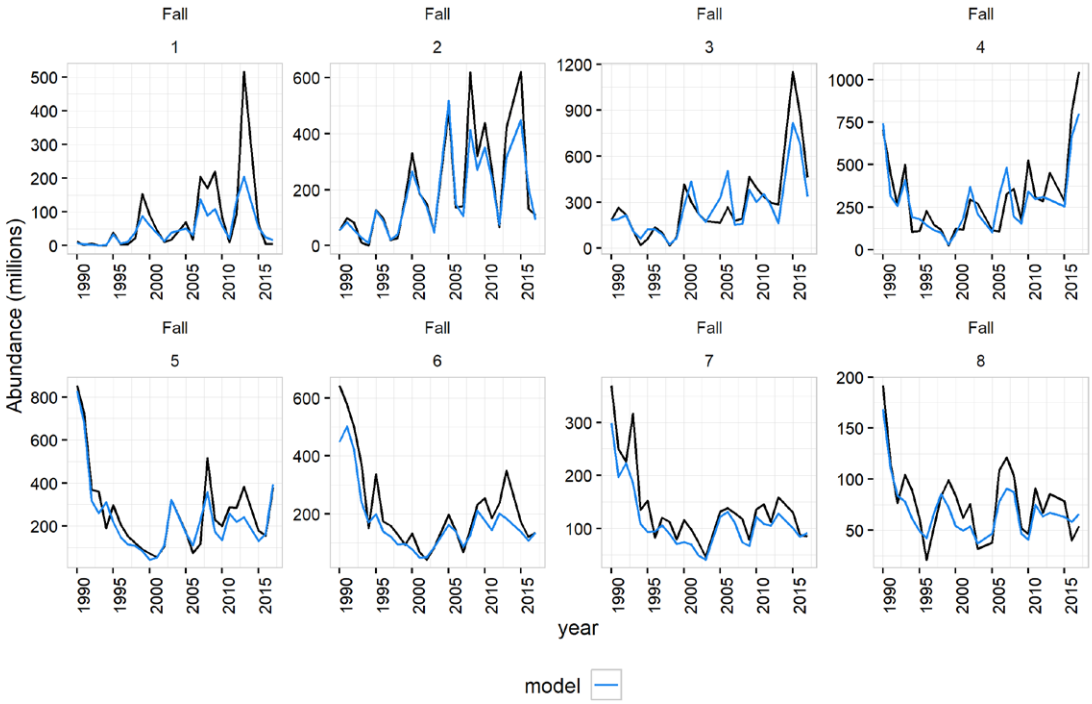


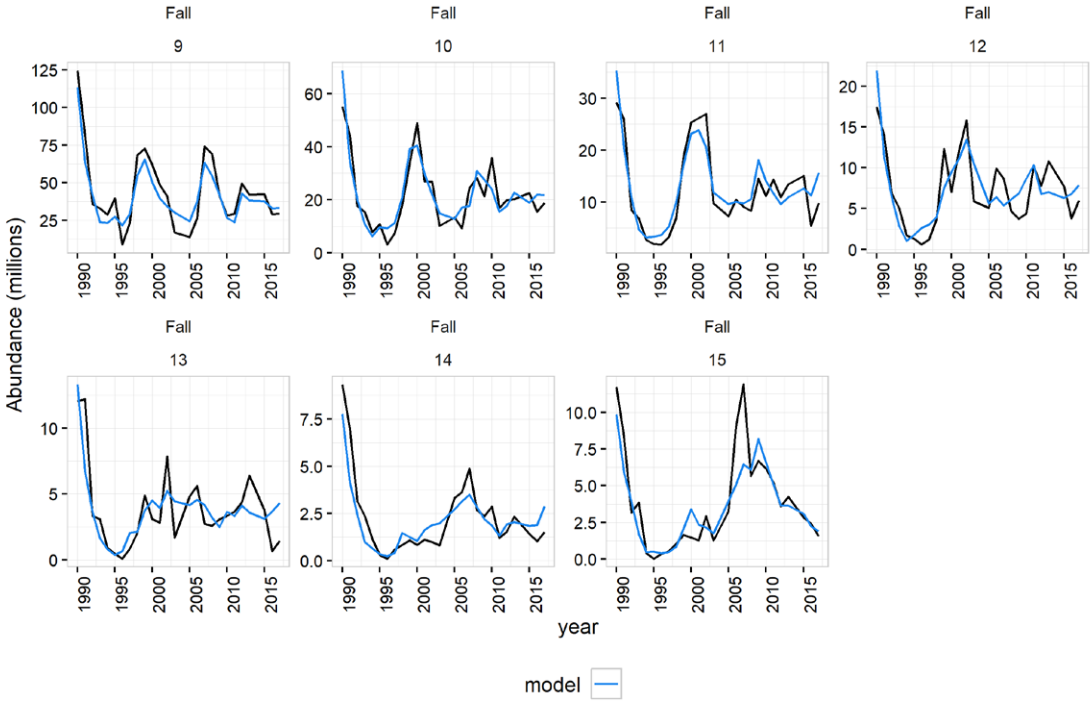
Estimated population processes



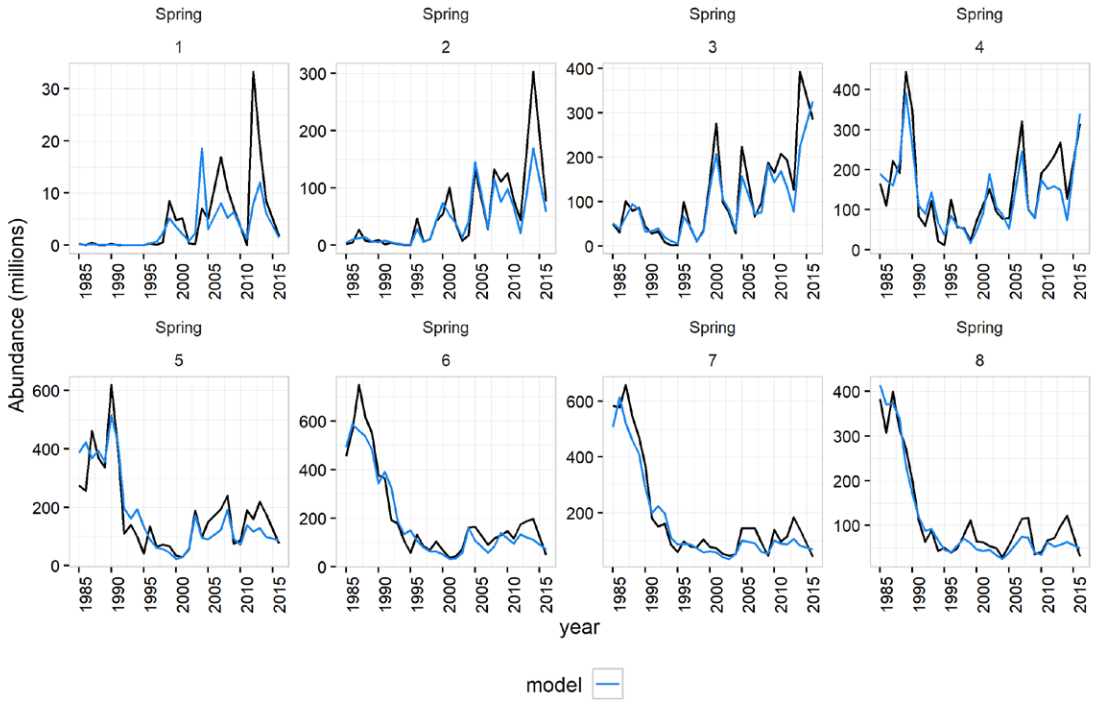
Survey fits

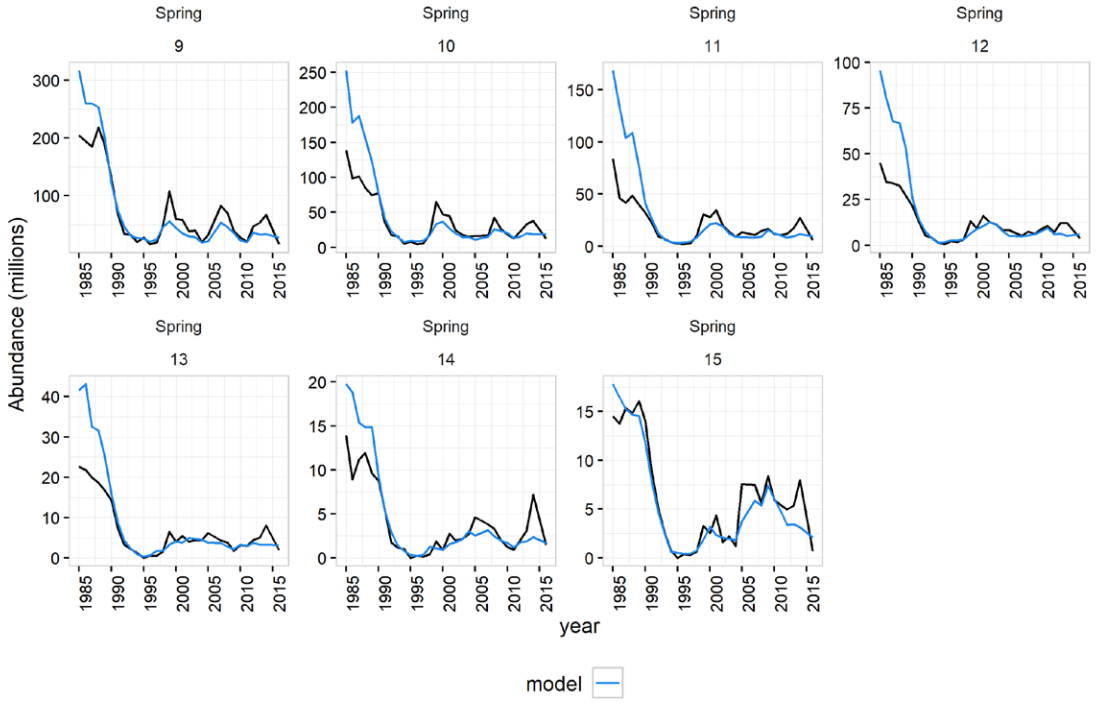
Fall



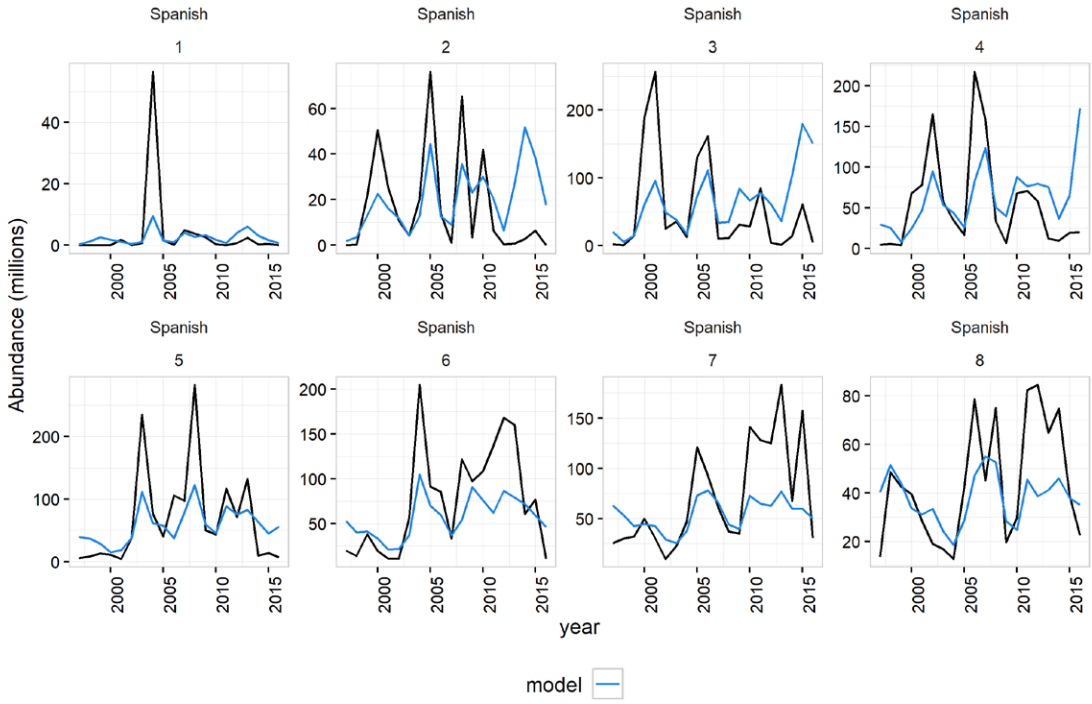


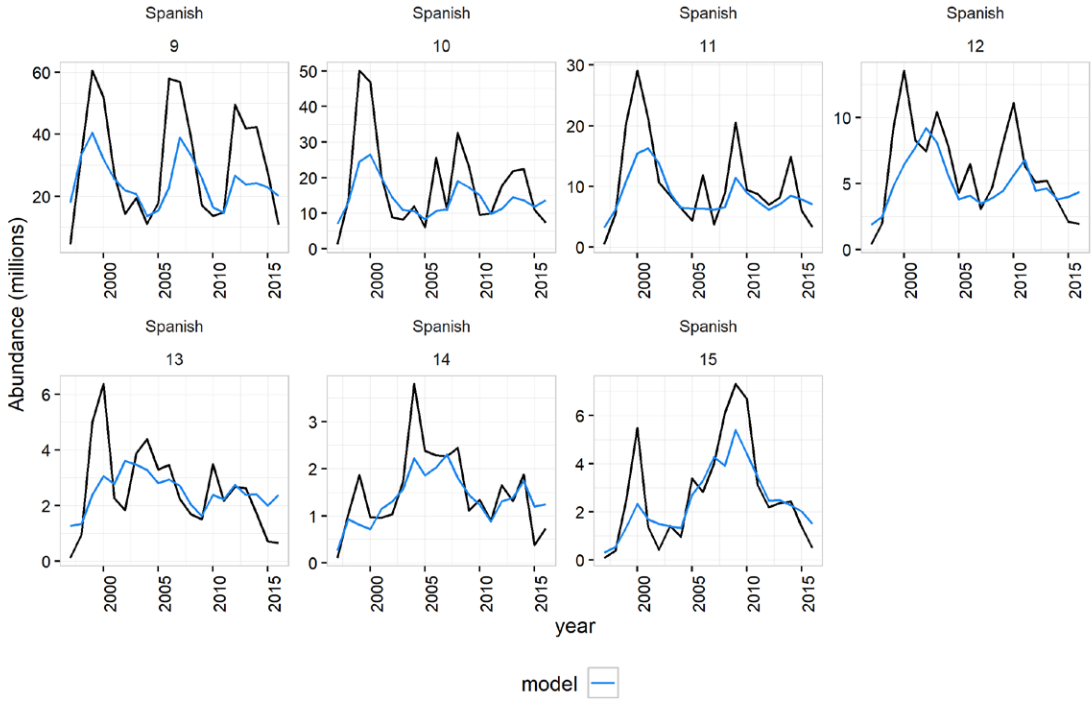
Spring


Spring
1
2
3
4
5
6
7
8
Abundance (millions)
year
model

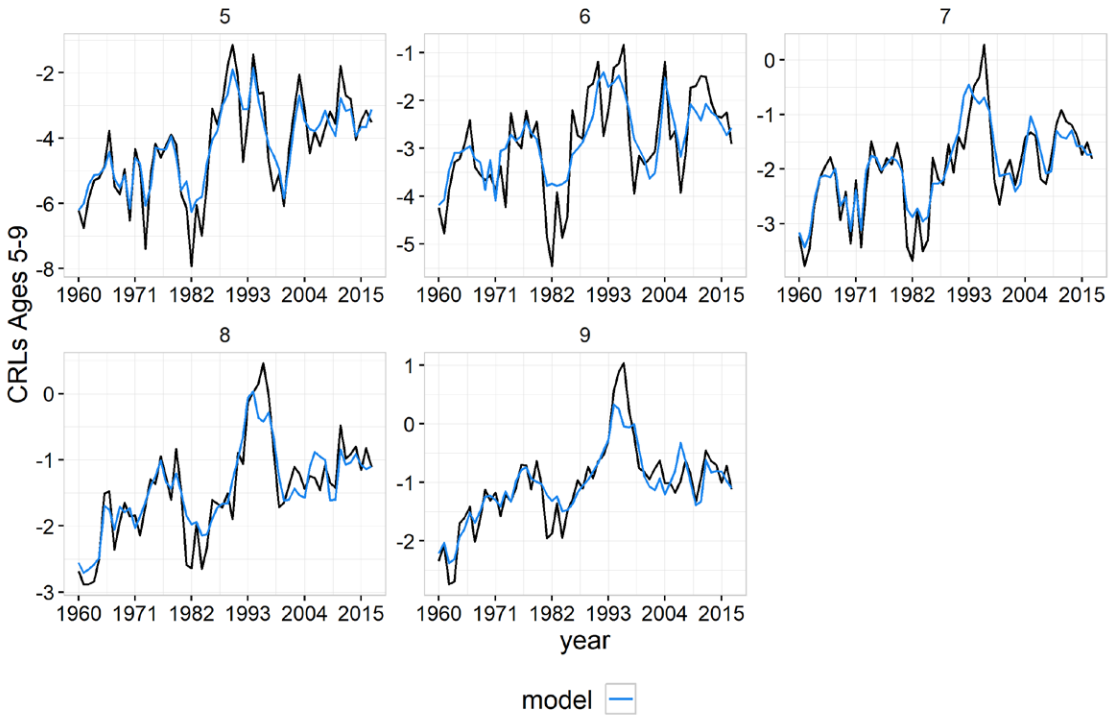

Spring
9
10
11
12
13
14
15
Abundance (millions)
year
model

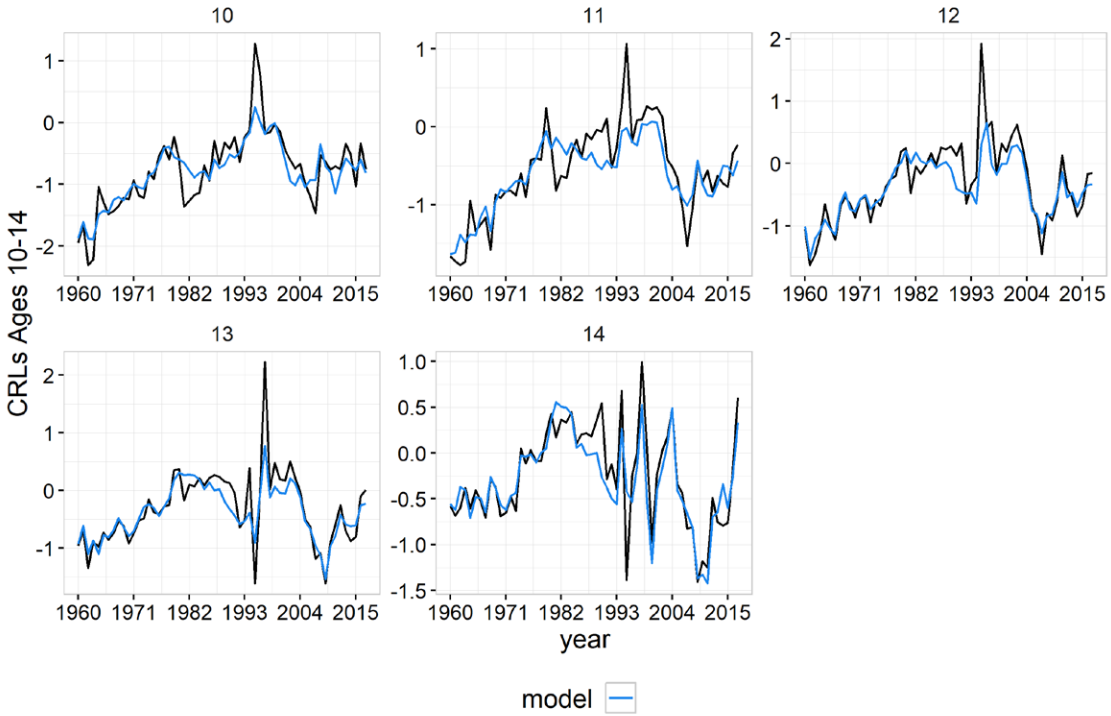
Spanish


Spanish
1
2
3
4
5
6
7
8
Abundance (millions)
year
model

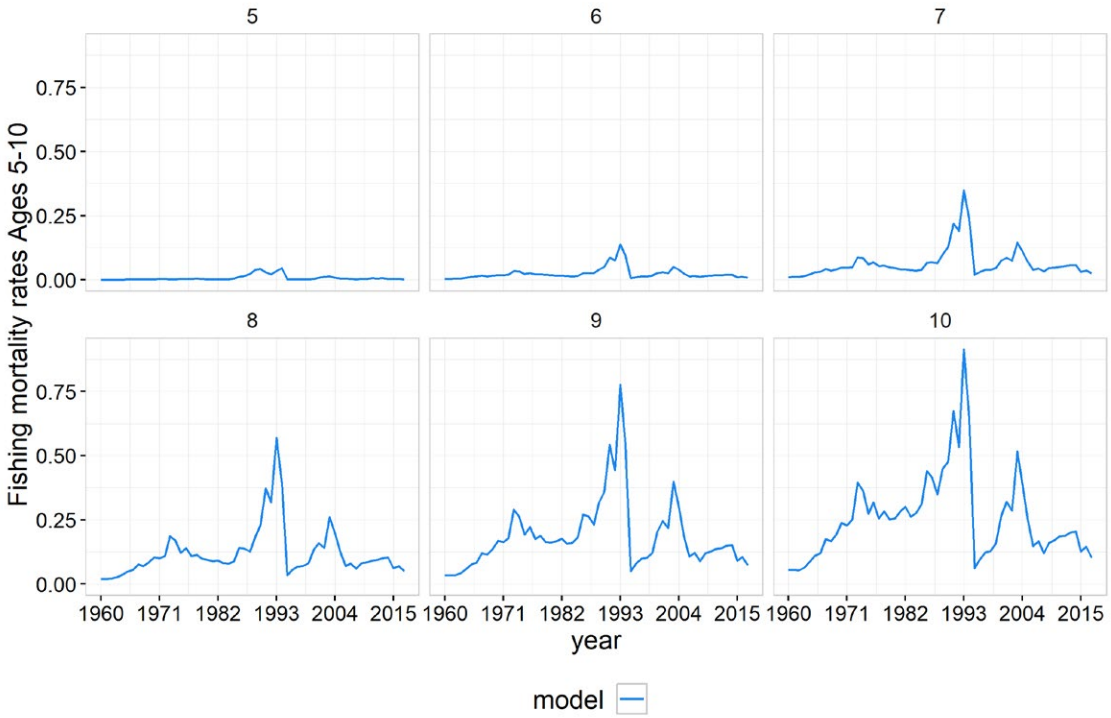

Spanish
9
10
11
12
13
14
15
Abundance (millions)
year
model

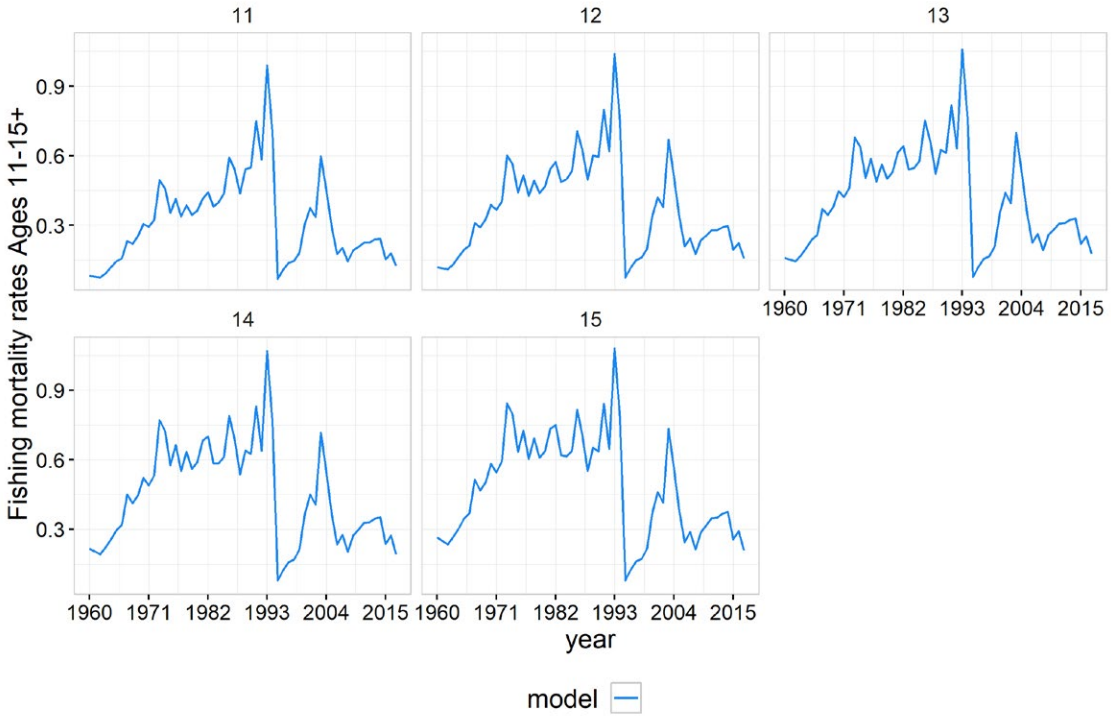
Crl fits

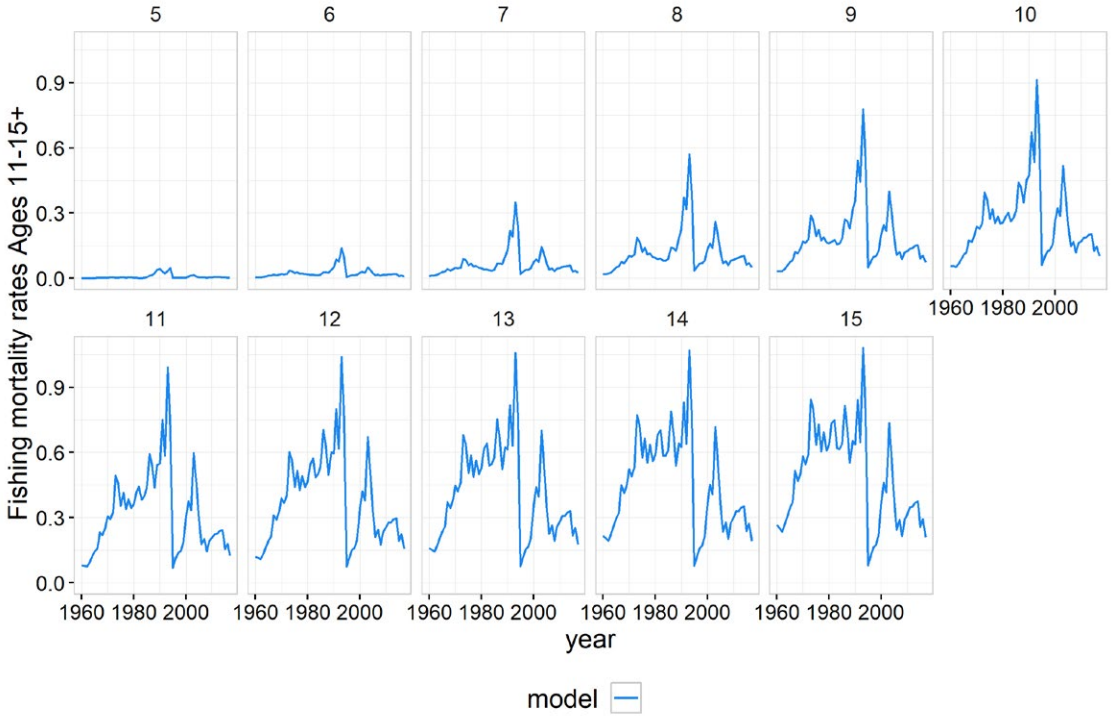

5
6
7
8
9
CRLs Ages 5-9
year
model


10
11
12
13
14
CRLs Ages 10-14
year
model

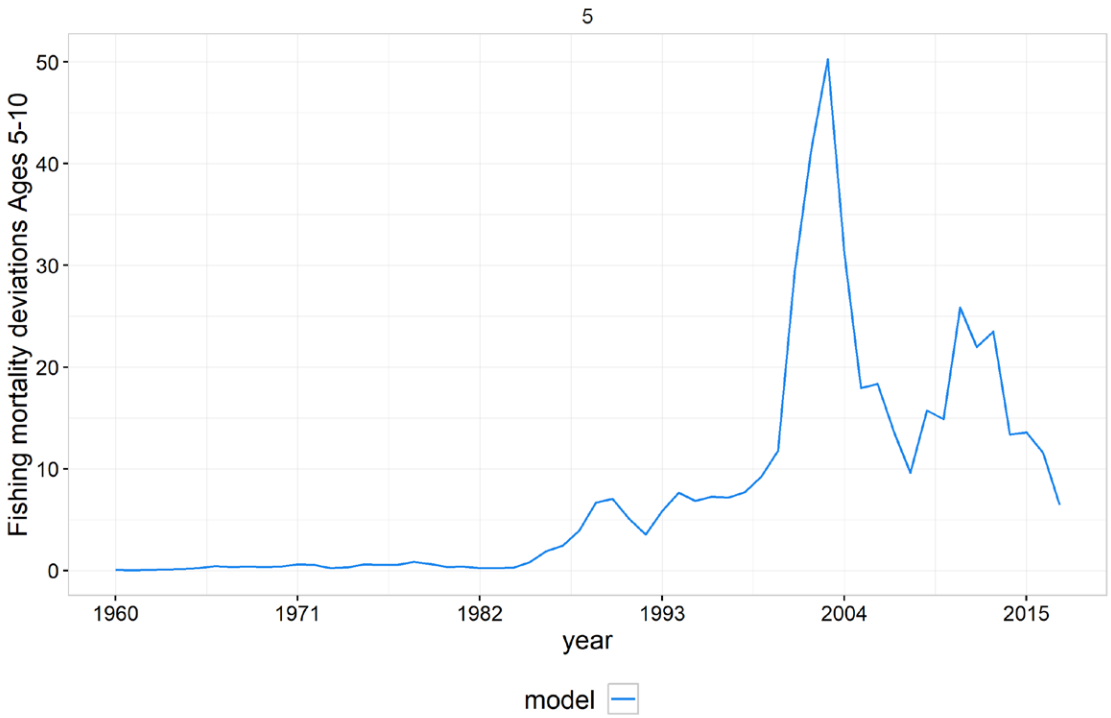
Fishing mortality rates

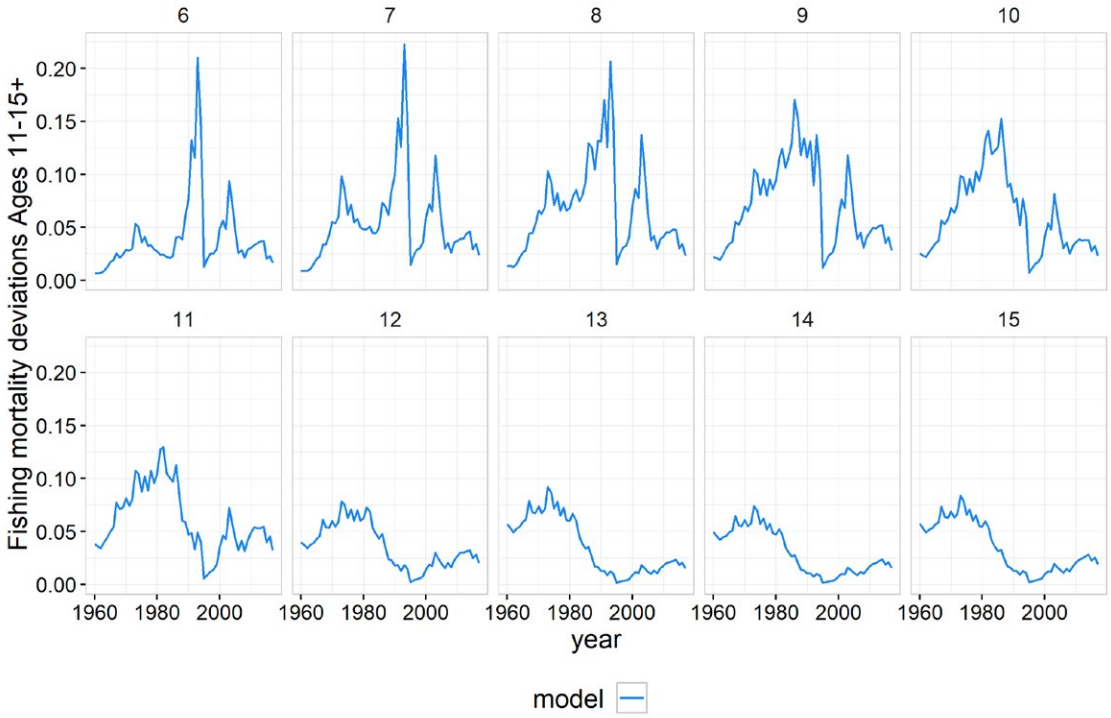




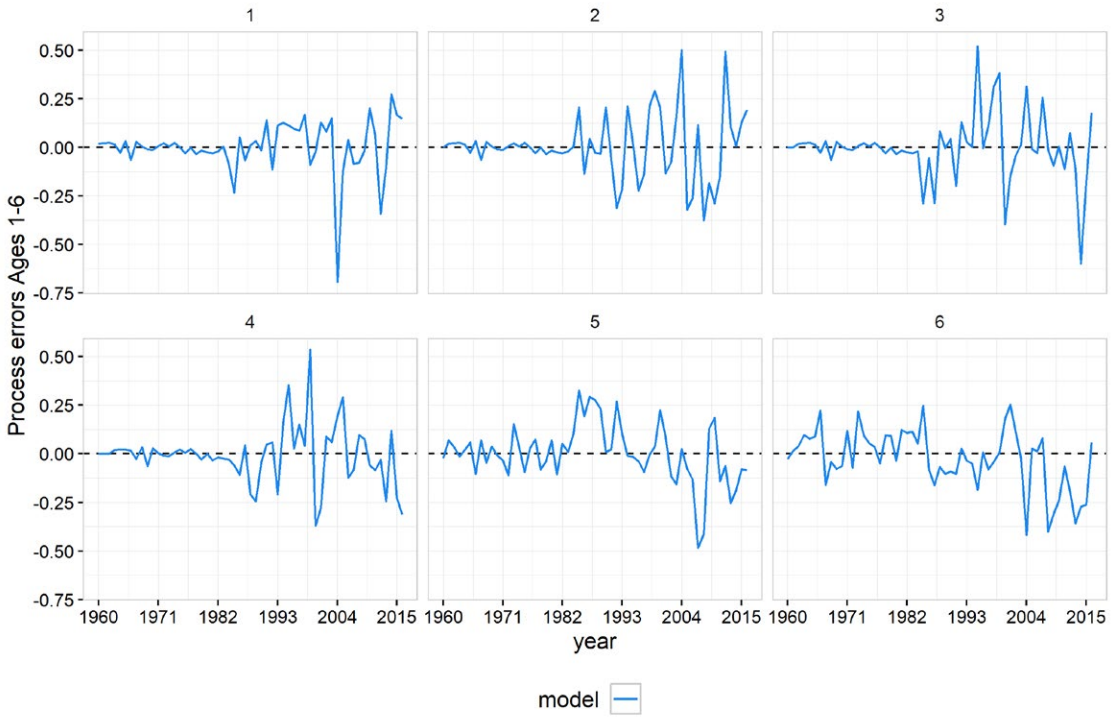

5
6
7
8
9
10
11
12
13
14
15
Fishing mortality rates Ages 11-15+
0.0
0.3
0.6
0.9
1960 1980 2000
year
model

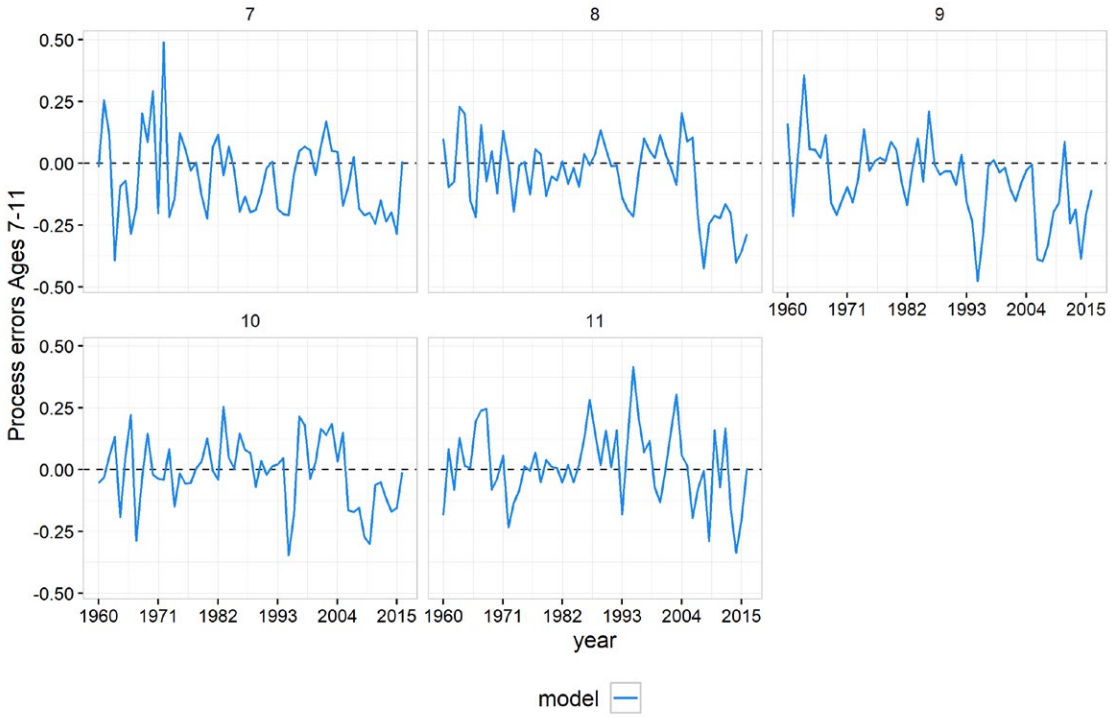
Fishing mortality deviations

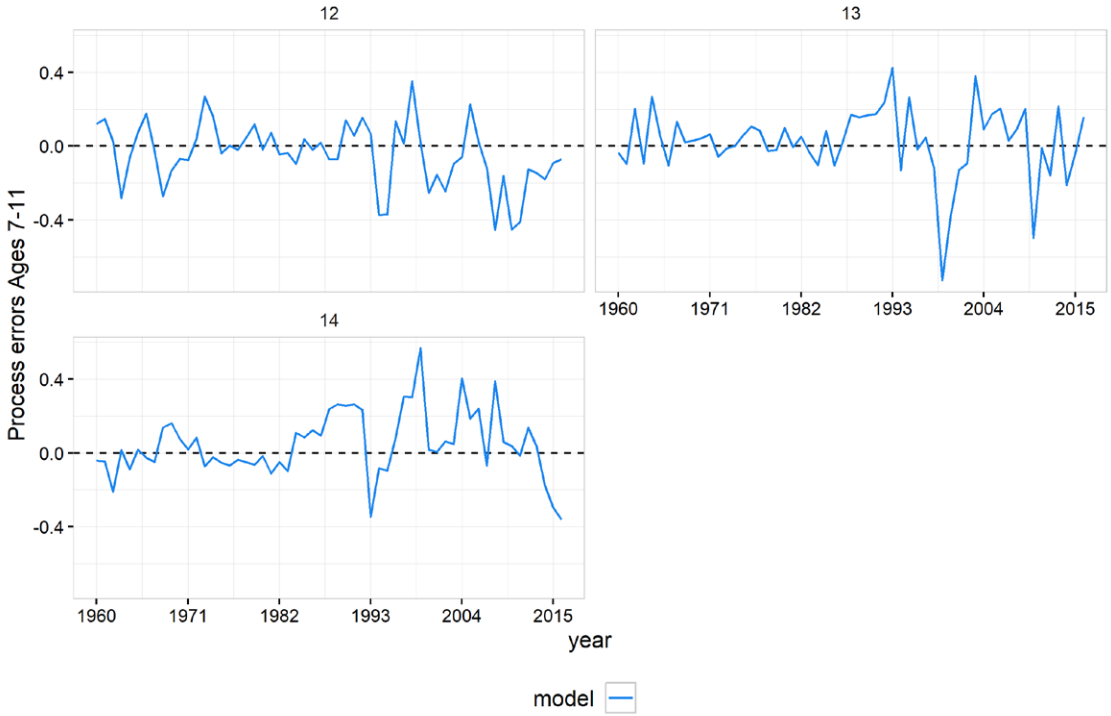




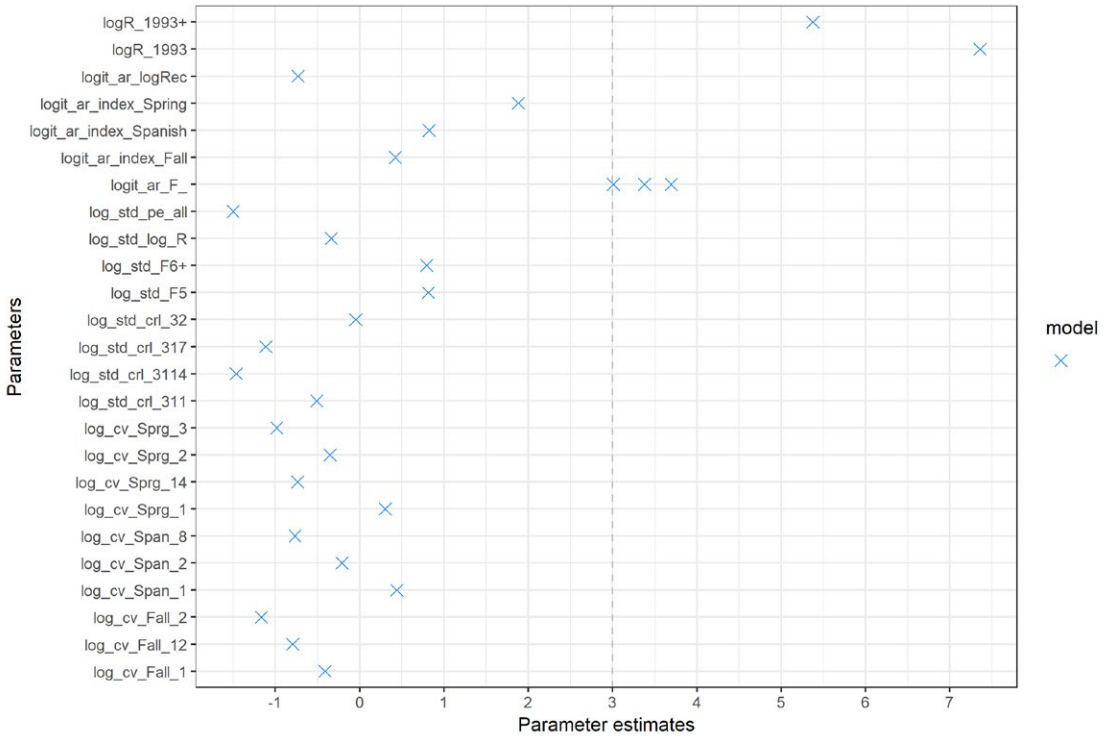
Process error





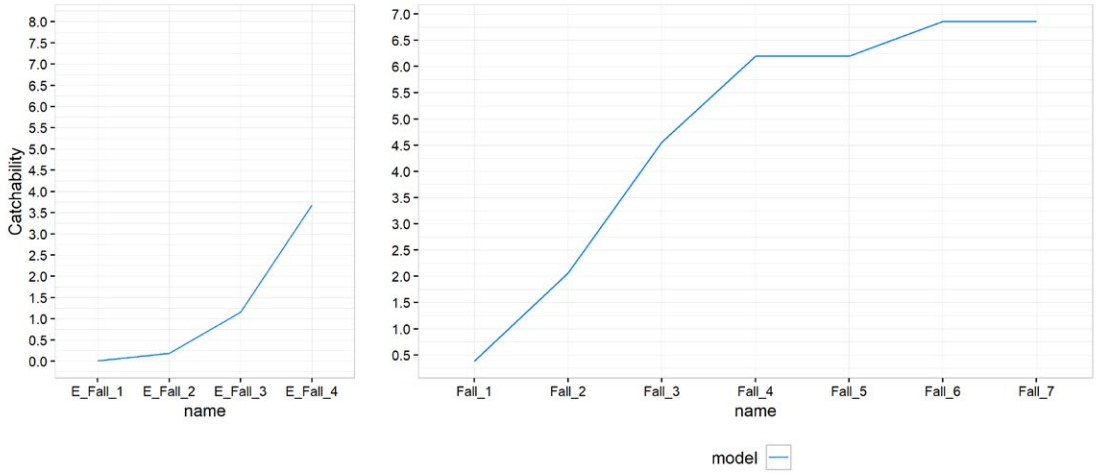


Parameter estimates

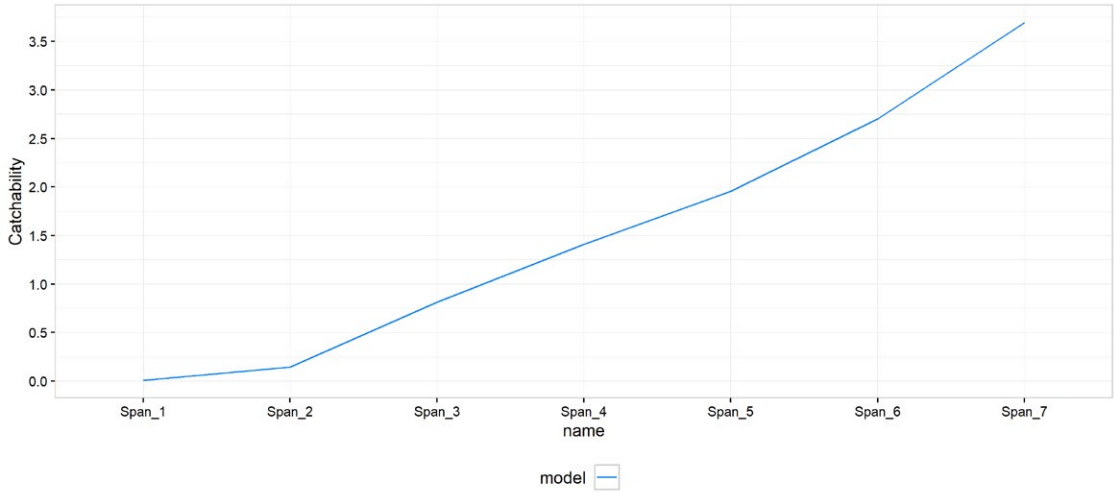


Catchability estimates

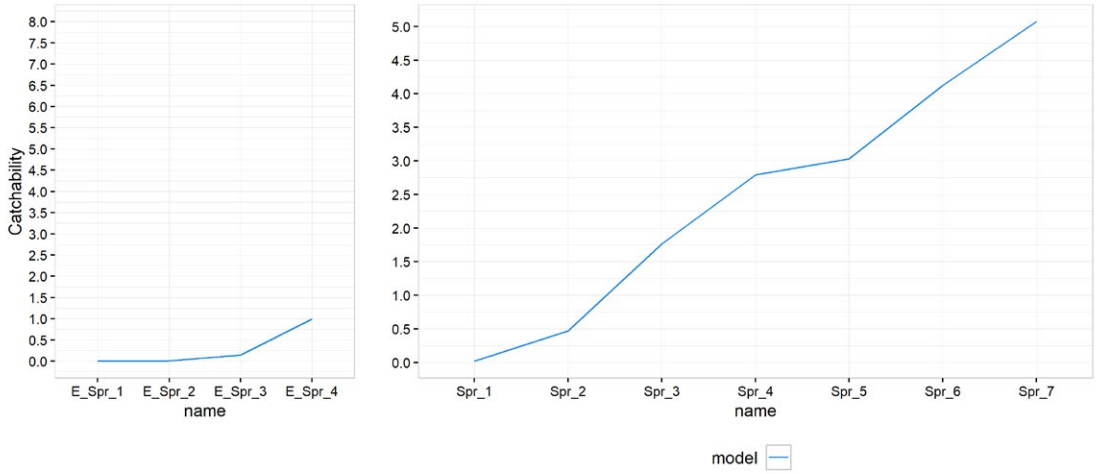
Fall



Spanish

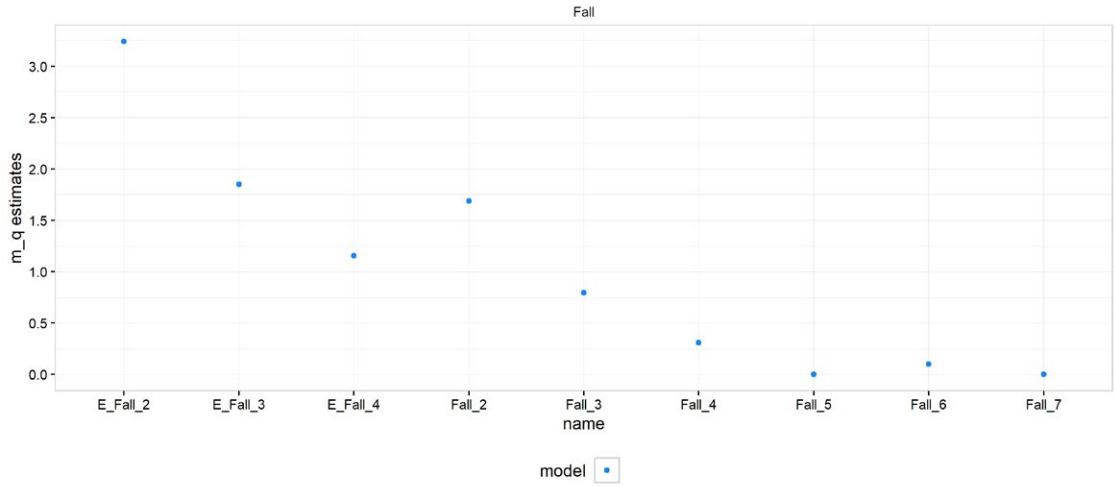


Spring

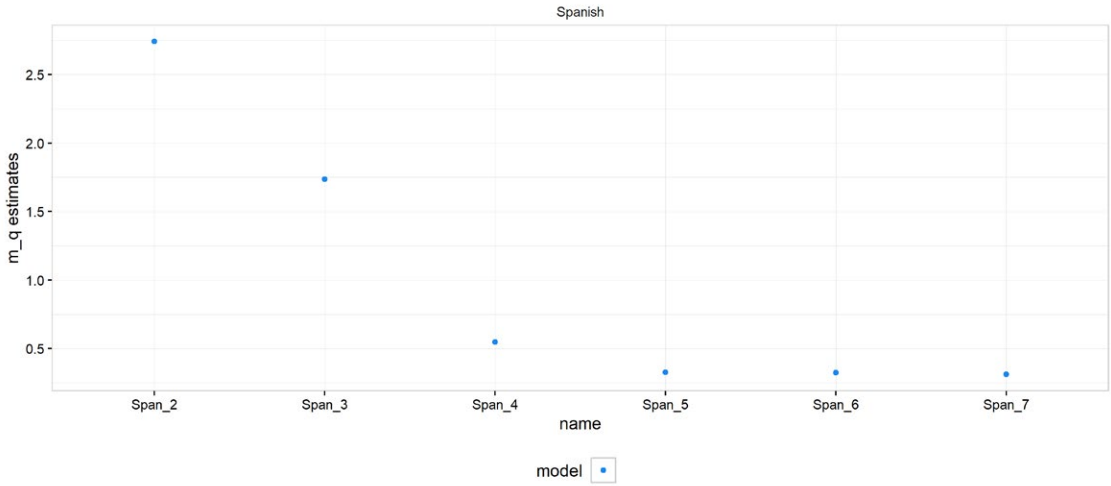


m_q estimates

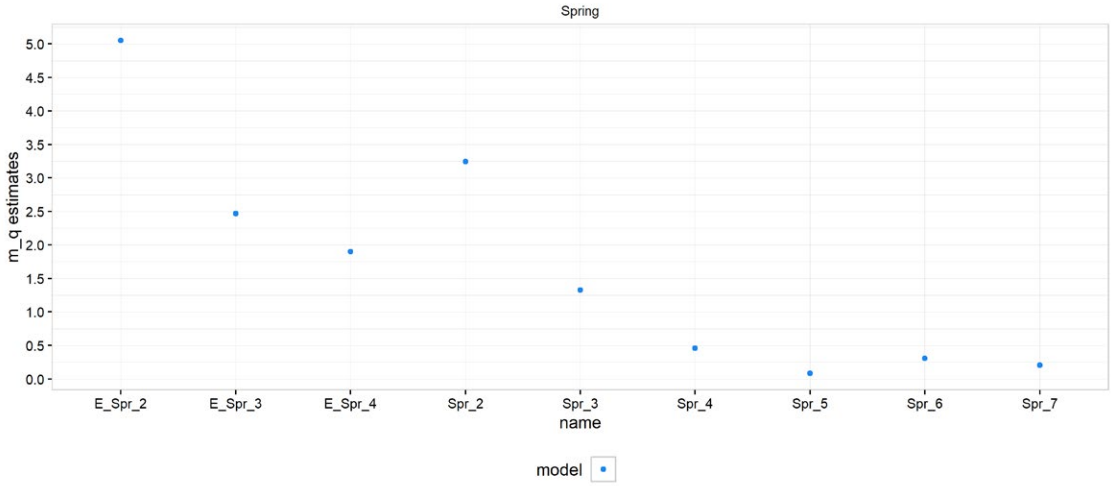
Fall



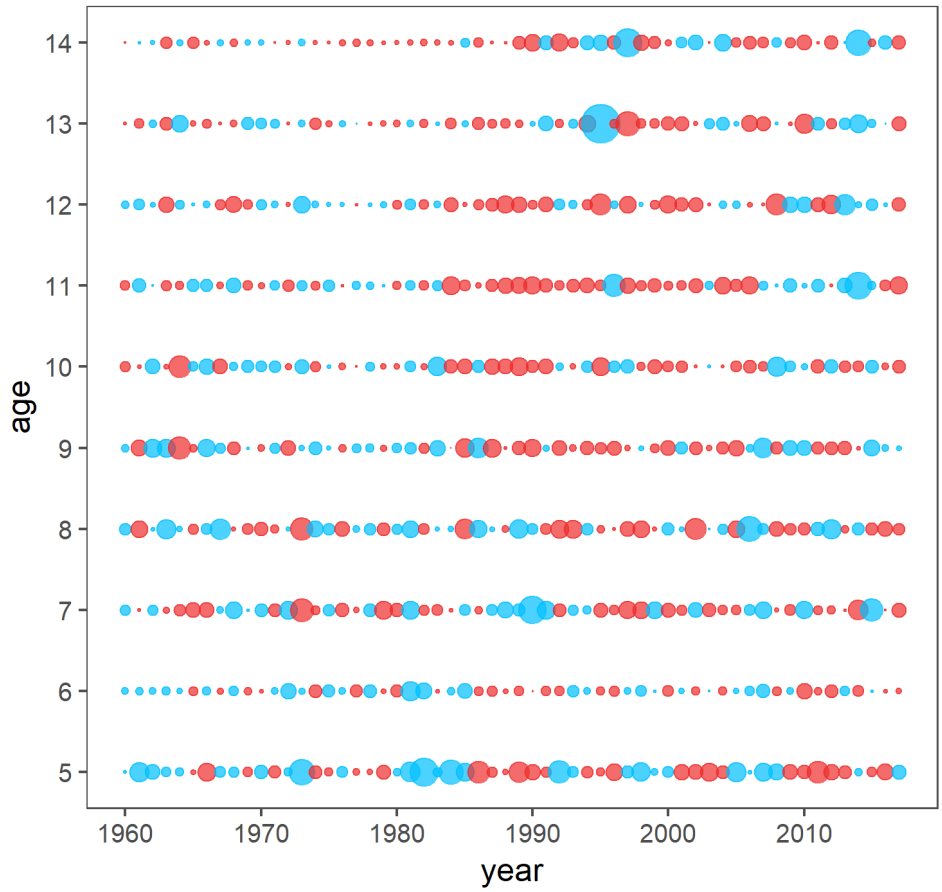
Spanish



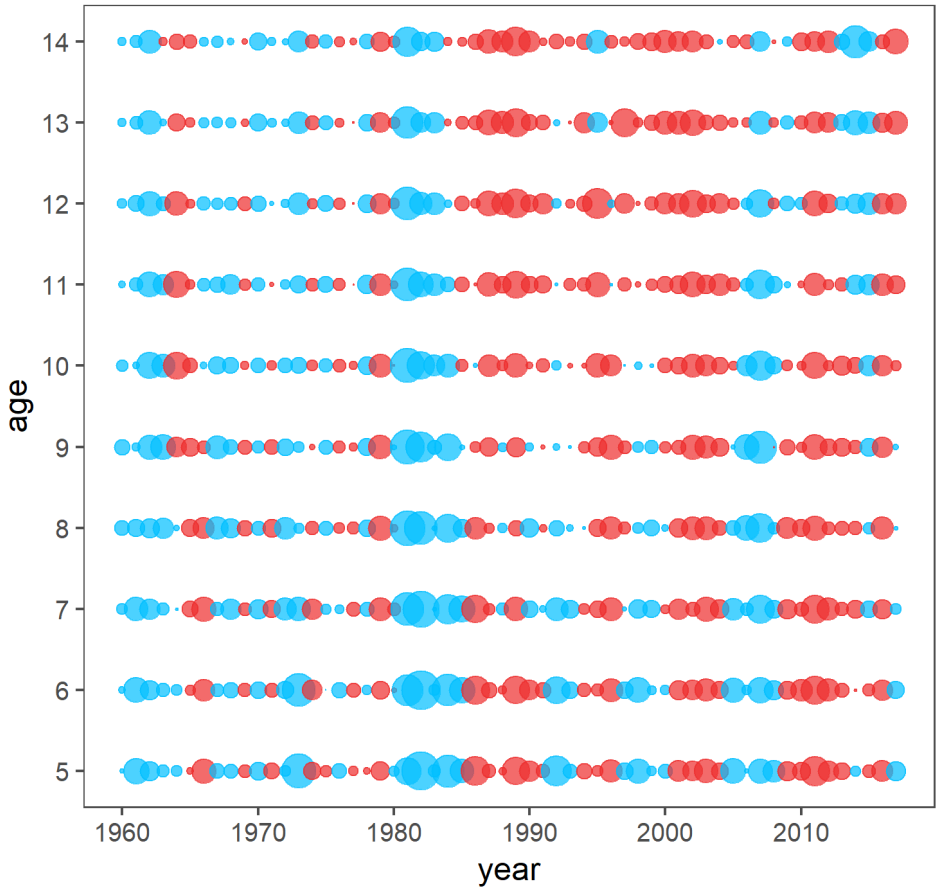
Spring



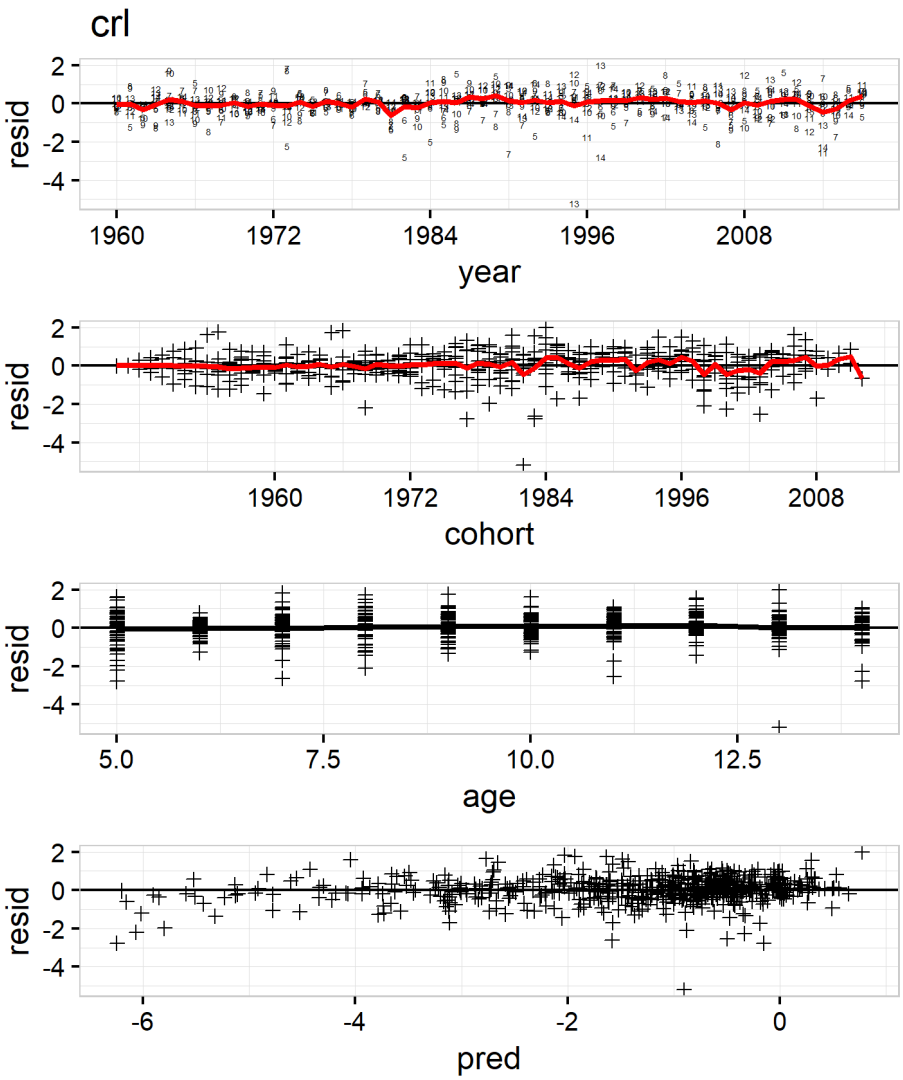
CRL residuals



Pearson CRL residuals



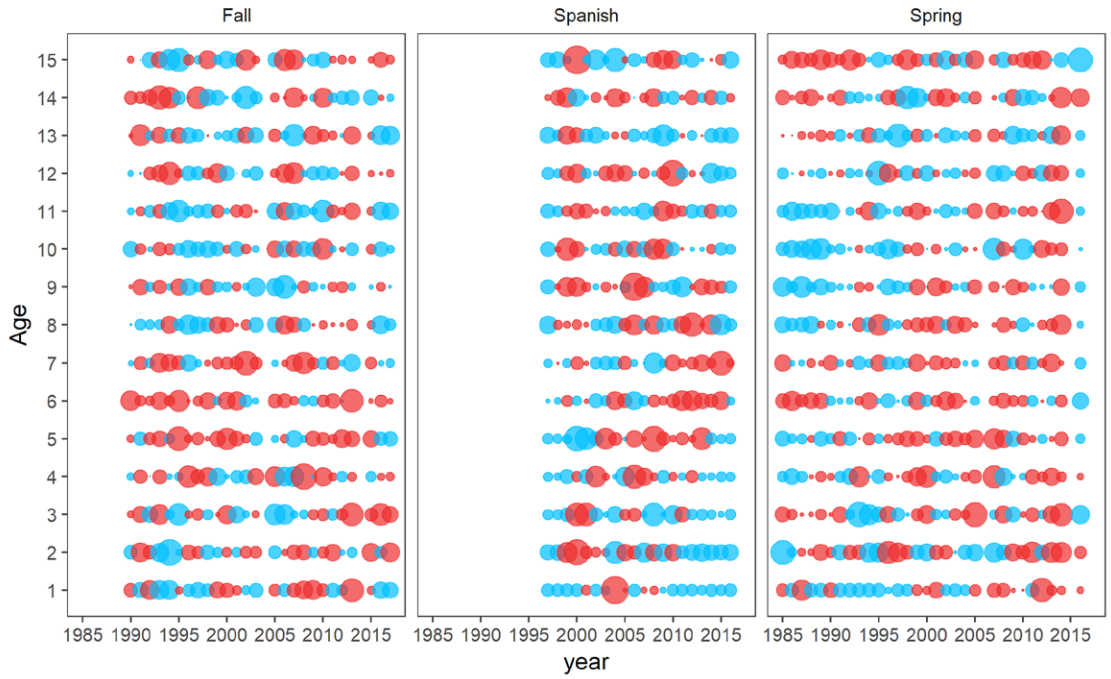
Four panel crl residuals



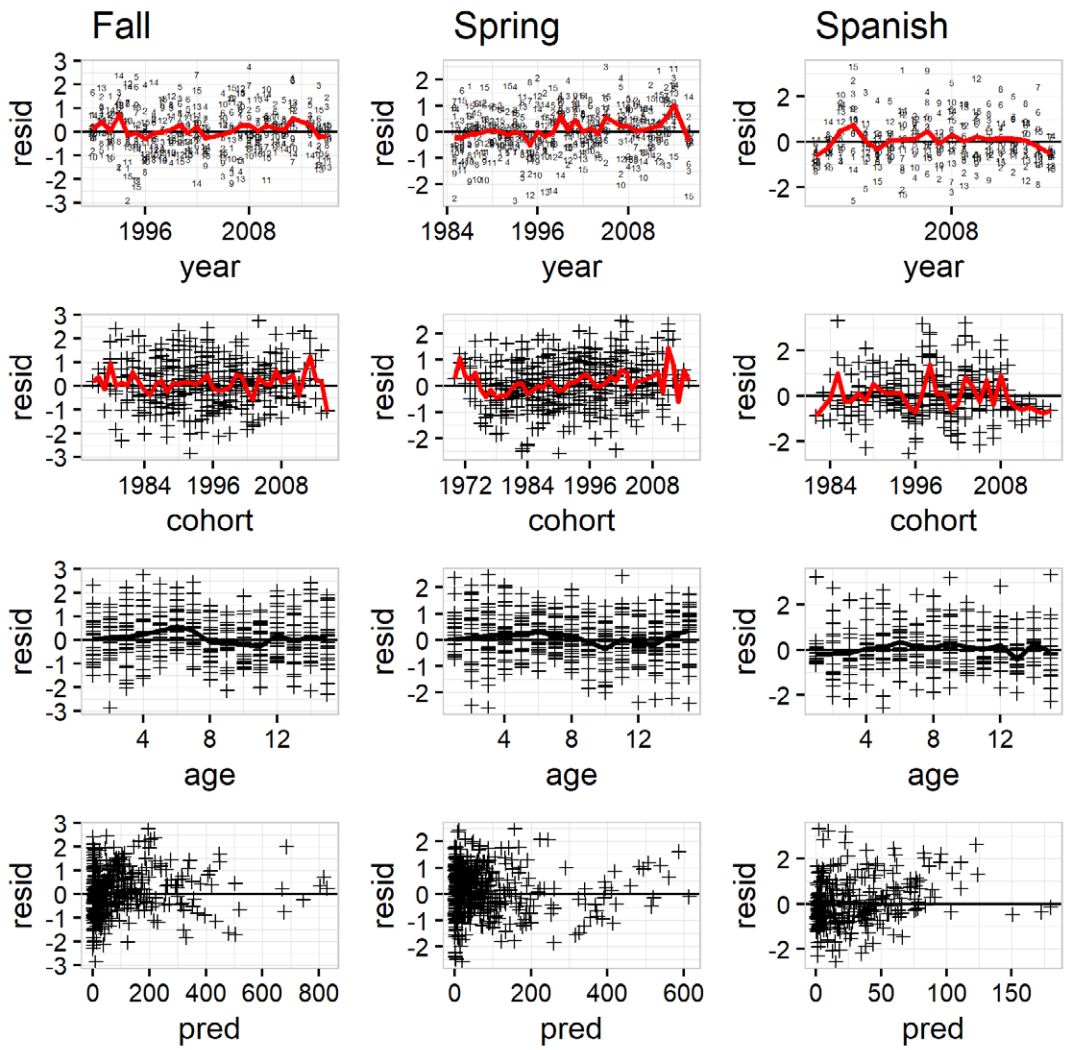
Survey residuals

Standardized survey residuals (red = positive, blue= negative)

Fall



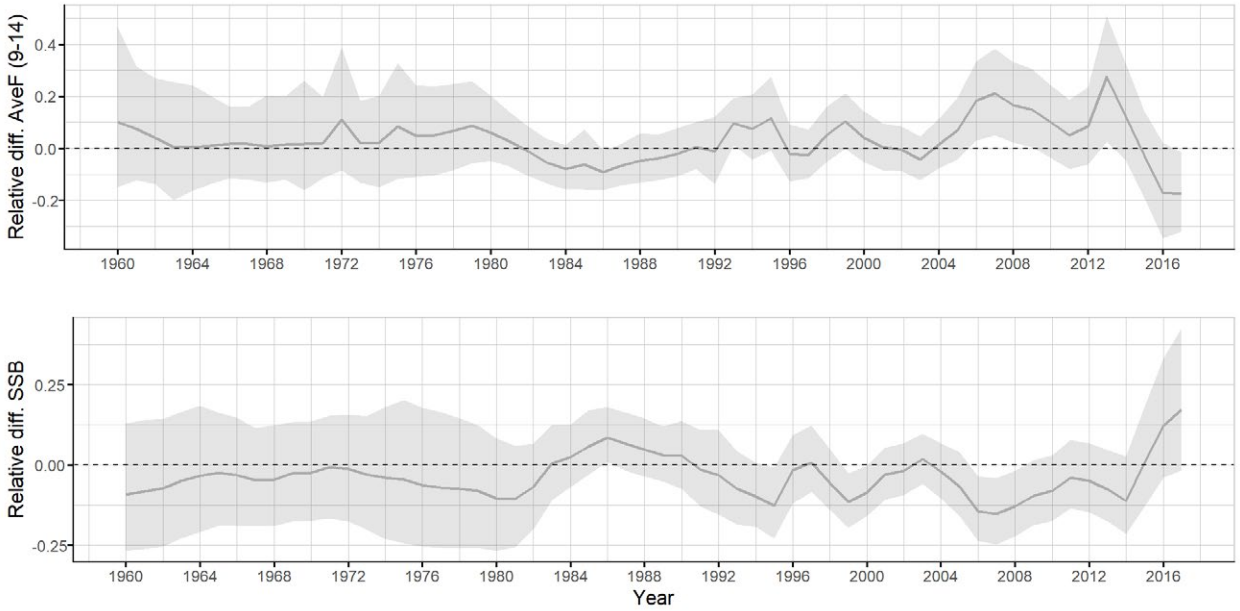
Four panel survey residuals



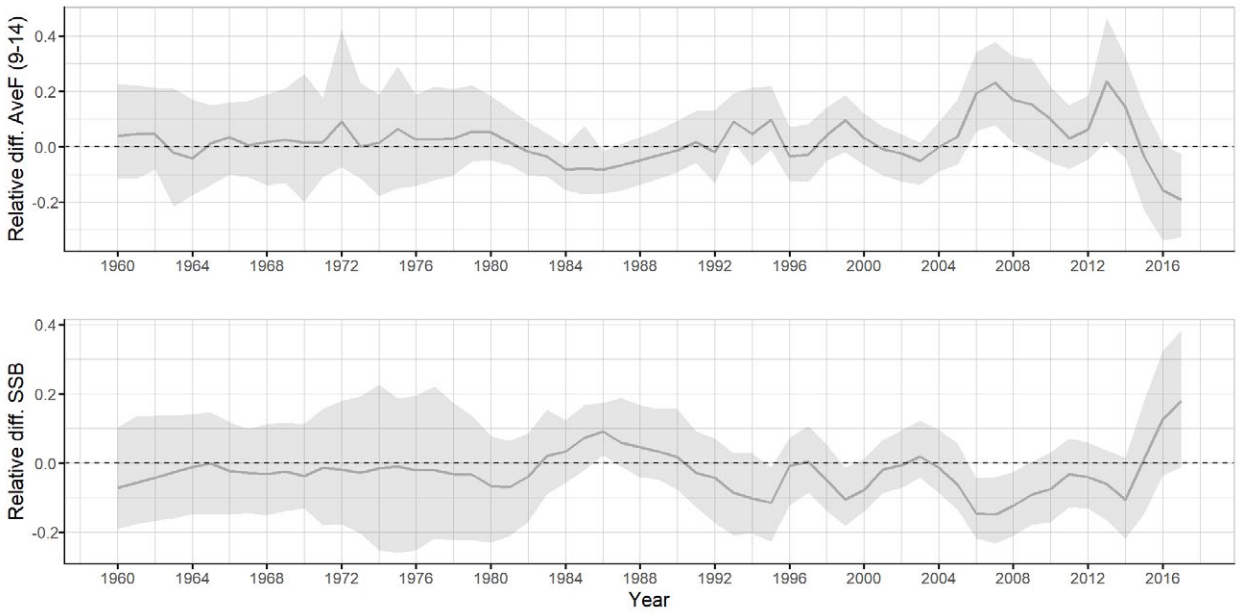
Supplementary Materials 4

Self-simulation runs

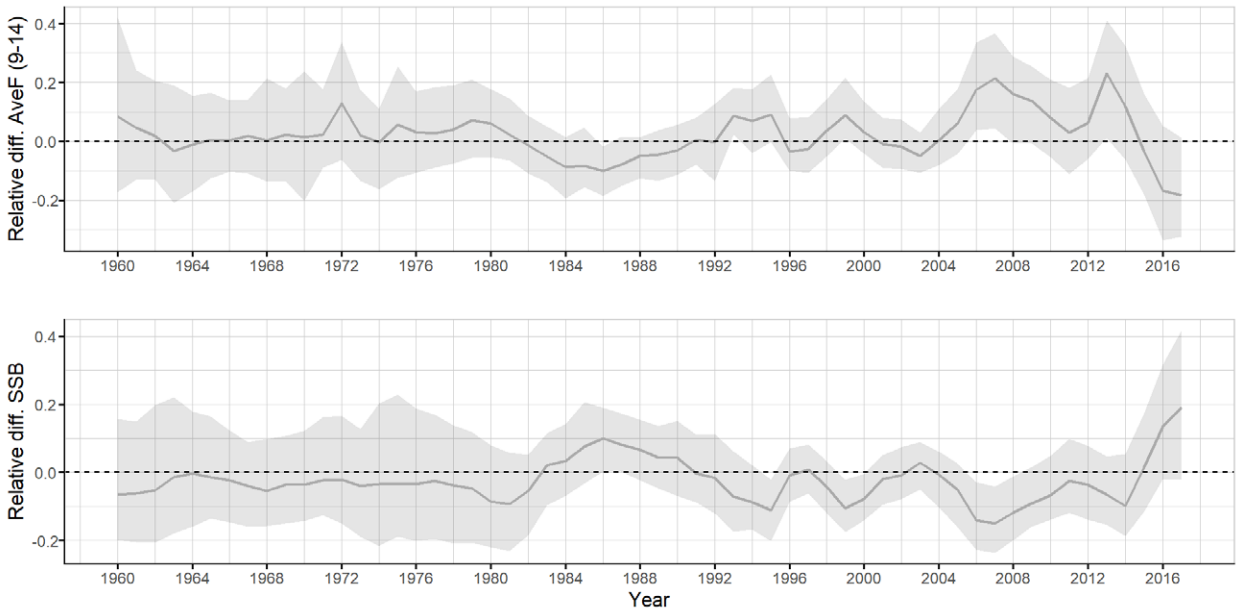
SSM



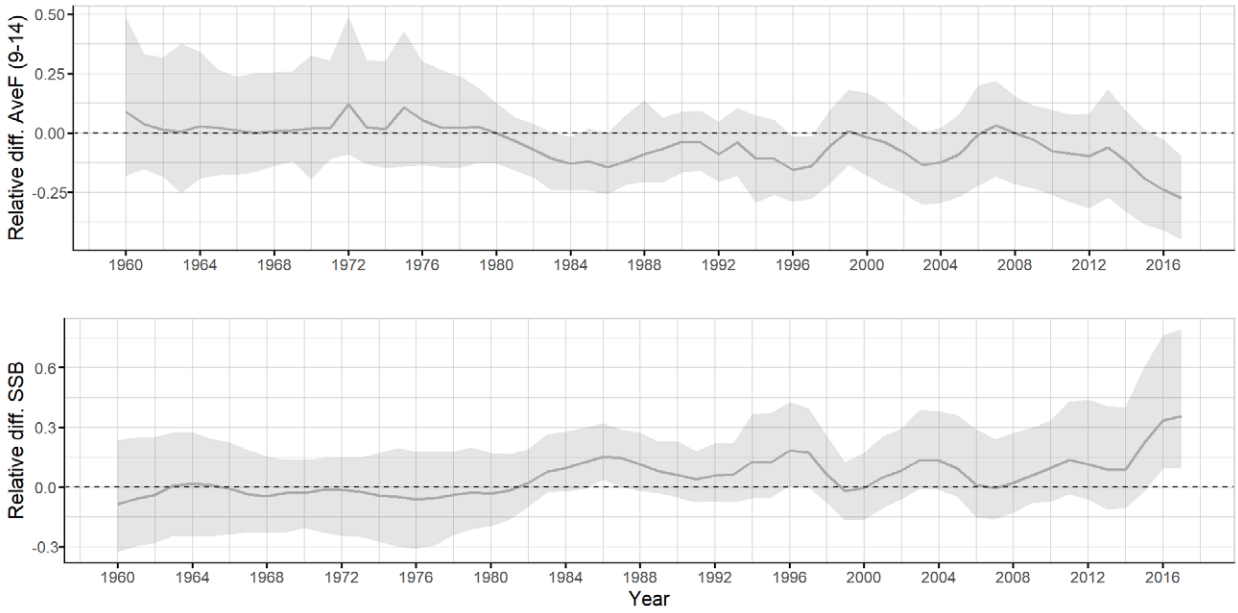
O1



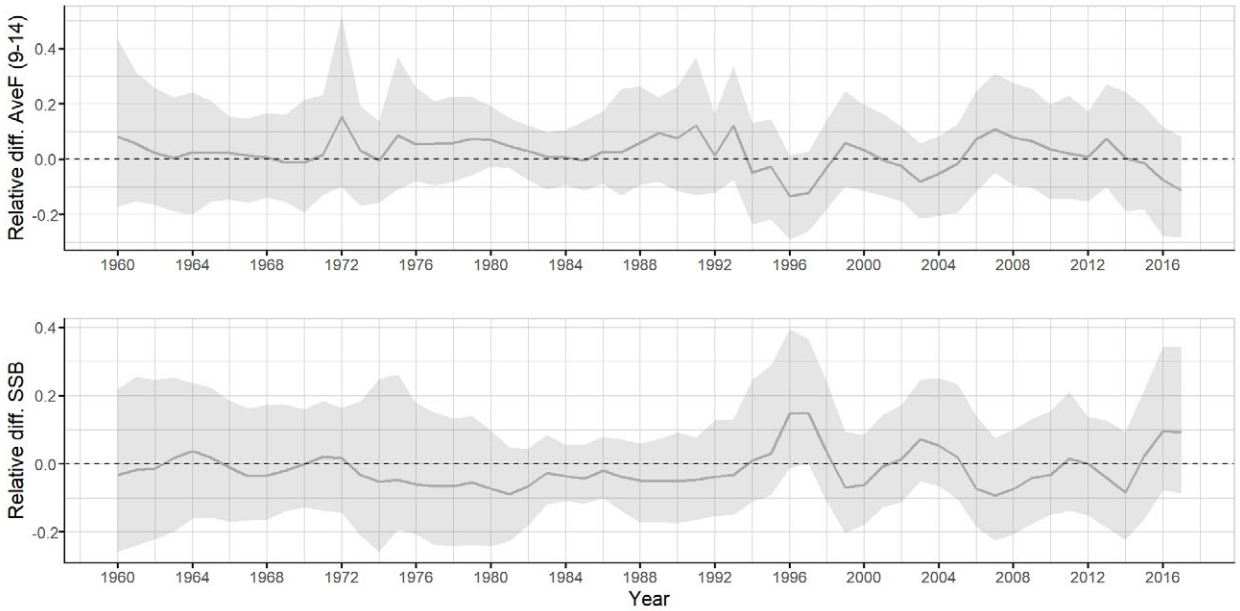
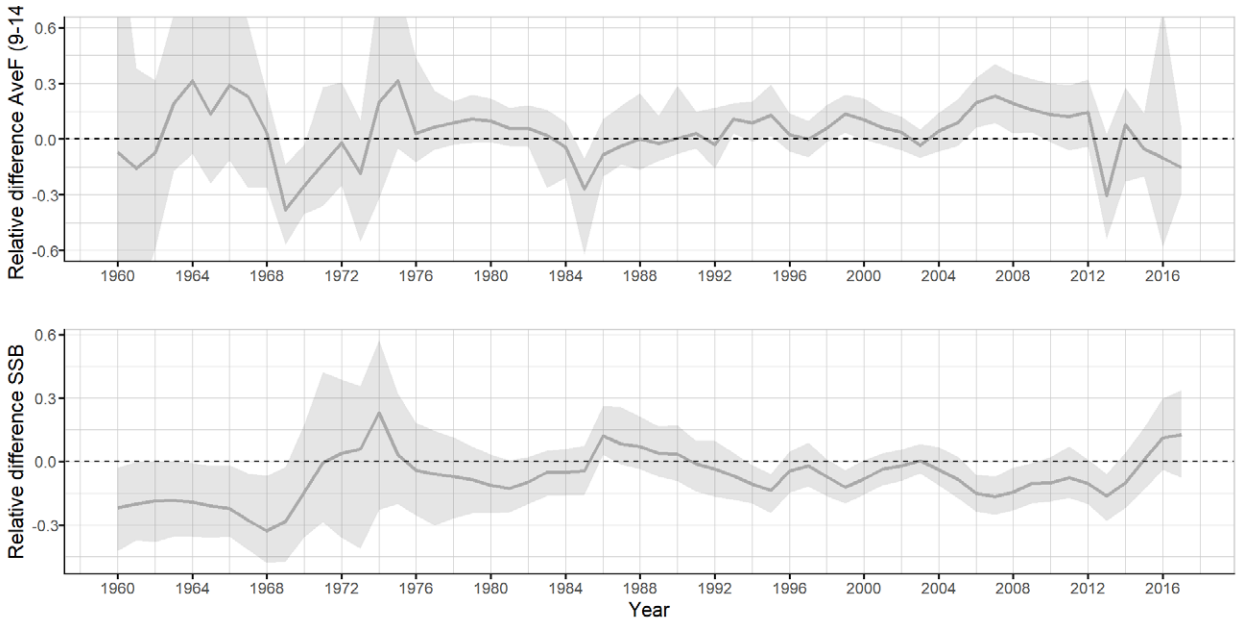
O2



SSM with $M_{a,y}$ = M + 0.20



SSM with $M_{a,y}$ = M + 0.33 for years 1989–2017; *i.e.* Morgan and Brodie increase for rest of time series



M4 (with TMB bias correction on)