Appendix A: Summarization of Fishery Data for Input to GMACS

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Retained Catch

Observed retained catch (t; $\hat{C}_{Ret,i}$) based on the status quo approach was computed as

$$\hat{C}_i = \sum_j w_j C_{RetN,i} P_{Ret,j,i} \tag{1}$$

where

w_j = average weight (t) of size bin j;
$C_{RetN,i}$ = total number of retained catch from fish ticket data, in year i;
$P_{Ret,j,i}$ = **retained catch** size composition proportion within size bin j, in year i.

Retained catch weight is recorded on fish tickets, and instead can be accessed directly and converted from lb to t (Table 2; Figure 1). Average weight of each size bin (w_j) used in the status quo approach is in Table (1).

Total Catch

Total catch in the directed fishery (t; $\hat{C}_{Tot,i}$) based on the status quo approach was computed as

$$\hat{C}_{Tot,i} = \sum_j w_j U_i n_i P_{Tot,j,i} \tag{2}$$

$$\bar{U}_i = \frac{1}{m_i} \sum_h^m c_{h,i} \tag{3}$$

where

U_i = observer catch per unit effort (CPUE; crab per pot) of male crab in the directed fishery in year i;
$c_{h,i}$ = number of male crab caught in observer of pot h, in year i;
n_i = total number of pot lifts in the directed fishery in year i;
m_i = number of observer pots sampled in year i;
w_j = average weight (t) of size bin j (Table 1);
$P_{Tot,j,i}$ = **total catch** (i.e., observer collected) size composition proportion within size bin j, in year i.

The updated approach computes $\hat{C}_{Tot,i}$ as

$$\hat{C}_{Tot,i} = \sum_k \bar{w}_{k,i} U_{k,i} n_i \tag{4}$$

$$U_{k,i} = \frac{1}{m_i}\sum_{h}^{m} c_{k,h,i} \tag{5}$$

$$\bar{w}_{k,i} = \frac{\sum \alpha L^{\beta} c_{l,k,i}}{\sum c_{l,k,i}} \tag{6}$$

where

$U_{k,i}$ = observer catch per unit effort (CPUE; crab per pot) in the directed fishery of group k (i.e., sublegal male, legal male), in year i;
$\bar{w}_{k,i}$ = mean weight (t) of crab caught in observer measure pots in group k, in year i;
$c_{k,h,i}$ = number of crab caught of group k,in observer of pot h, in year i;
$c_{l,k,i}$ = number of crab caught of carapace length l, in group k, in year i;
L = carapace length;
α = allometric scale parameter ($\alpha = 0.0001445$);
β = allometric shape parameter ($\beta = 3.28113$).

Comparison of estimates is found in Table 3 and Figure 2.

Coefficient of variation (cv) for total catch in each year is the graded number of observer sampled pots with non-zero catches ($m_{nz,i}$) in which the maximum weight (ω_i) is max$[\omega_i] = 250$, scaled as

$$cv_i = \sqrt{e^{\frac{1}{2\omega_i}} - 1} \tag{7}$$

$$\omega_i = \frac{\max[\omega_i] m_{nz,i}}{\max[m_{nz,i}]} \tag{8}$$

The number of observer sampled pots with non-zero catches listed in the data file of the legacy model does not match that accessed from the observer program database. Status quo and updated timeseries of $m_{nz,i}$ and cv_i are listed Table (4).

Retained Catch Length Composition

Length composition of the retained catch based on the status quo approach was estimated as

$$P_{Ret,j,i} = \frac{\sum_k x_{j,k,i} C_{k,i}}{\sum_j \sum_k x_{j,k,i} C_{k,i}} \tag{9}$$

where

$P_{Ret,j,i}$ = the estimated proportion of retained crab in size bin j, and year i;
$x_{j,k,i}$ = the number of crab measured in size bin j, during delivery k, in year i;
$C_{k,i}$ = the catch (i.e., number of crab off-loaded) from fish ticket k, in year i.

The updated approach does not weight $x_{j,k,i}$ by fish ticket report catch, thus $C_{k,i} = 1$ (Figure 3). Stage 1 effective sample sizes ($\lambda_{Ret,i}$) are calculated as the total number of vessel days in the directed fishery, though $\lambda_{Ret,i}$ listed in the data file of the legacy model does not match that computed from fish ticket data in each year. Since the total number of vessel days is not strongly related to retained catch sampling effort, model 23.1a evaluated effective sample size based on the number of deliveries sampled (Table 5; Figure 5).

Total Catch Length Composition

Length composition of the total catch based on the status quo approach was estimated as

$$P_{Tot,j,i} = \frac{\sum_h x_{j,h,i} C_{k,i}}{\sum_j \sum_h x_{j,h,i} C_{k,i}} \tag{10}$$

where

$P_{Tot,j,i}$ = the estimated proportion of the total catch in size bin j, and year i;
$x_{j,k,i}$ = the number of crab measured by observers in size bin j, pot h, and year i;
$C_{k,i}$ = the catch (i.e., number of crab off-loaded) from fish ticket k corresponding to each observer pot, in year i.

As with the retained catch length composition, the updated approach does not weight $x_{j,k,i}$ by fish ticket report catch, thus $C_{k,i} = 1$ (Figure 6). Stage 1 effective sample sizes ($\lambda_{Tot,i}$) are calculated as the total number of vessel days in the directed fishery, though $\lambda_{Tot,i}$ listed in the data file of the legacy model does not match that computed from observer data in each year (Table 6).

Groundfish Bycatch

Groundfish fixed and trawl gear fishery bycatch mortality (t; $\hat{C}_{GF,i}$) based on the status quo approach was computed as

$$\hat{C}_{GF,i} = \sum_j w_j \hat{C}_{GFN,i} P_{GF,j,i} \tag{11}$$

where

$\hat{C}_{GFN,i}$ = estimated bycatch mortality of male crab (i.e., number of crab) in year i;
w_j = average weight (t) of size bin j (Table 1);
$P_{Tot,j,i}$ = **groundfish fisheries bycatch** (i.e., observer collected) size composition proportion within size bin j, in year i.

Estimated bycatch mortality numbers ($\hat{C}_{GFN,i}$) were computed by multiplying the estimated total bycatch accessed from AKFIN reports by the mortality rate associated with gear type (i.e., 0.5 for fixed gear and 0.8 for trawl gear) (Table 7; Figure **??**). Cahalan et al., (2014) details the method for extrapolation of observer sampled hauls to obtain $\hat{C}_{GFN,i}$. The updated approach accesses expanded $\hat{C}_{GF,i}$ directly from AKFIN reports and applies a mortality rate of 0.5 to fixed gear fisheries and 0.8 to trawl gear fisheries, whereas the status quo approach considered only bycatch from observed hauls. NMFS reporting areas 518 (EAG), 519 (EAG), 541 (EAG), 542 (WAG) and 543 (WAG) were used for this stock in data from 1991 - 2008.

Tables

Table 1: Weight at size (w_j) in kg used by the status quo approach to estimate retained catch, total catch and groundfish fishery bycatch.

Bin	Mid CL (mm)	w_j
100 - 105	103	0.582
105 - 110	108	0.679
110 - 115	113	0.788
115 - 120	118	0.908
120 - 125	123	1.041
125 - 130	128	1.186
130 - 135	133	1.345
135 - 140	138	1.518
140 - 145	143	1.706
145 - 150	148	1.910
150 - 155	153	2.129
155 - 160	158	2.366
160 - 165	163	2.621
165 - 170	168	2.894
170 - 175	173	3.186
175 - 180	178	3.499
180 - 185	183	3.994

Table 2: Timeseries of directed fishery retained catch (t) computed using the status quo approach and accessed directly from fish tickets.

	Status Quo		Update	
Year	EAG	WAG	EAG	WAG
1985/86	2,730	2,030	2,955	2,821
1986/87	2,845	4,272	2,686	3,999
1987/88	1,909	2,535	2,010	2,189
1988/89	2,424	2,471	2,335	2,485
1989/90	2,777	3,063	2,666	3,024
1990/91	1,637	1,636	1,688	1,615
1991/92	2,026	1,359	2,035	1,397
1992/93	2,125	1,030	2,112	1,025
1993/94	1,421	669	1,439	686
1994/95	2,038	1,626	2,044	1,540
1995/96	2,224	1,192	2,259	1,203
1996/97	1,624	1,237	1,738	1,259
1997/98	1,481	1,067	1,588	1,083
1998/99	1,415	935	1,473	955
1999/00	1,335	1,240	1,392	1,222
2000/01	1,359	1,385	1,422	1,342
2001/02	1,401	1,288	1,442	1,243
2002/03	1,243	1,217	1,280	1,198
2003/04	1,297	1,249	1,350	1,220
2004/05	1,270	1,266	1,309	1,219
2005/06	1,272	1,238	1,300	1,204
2006/07	1,390	1,056	1,357	1,030
2007/08	1,329	1,242	1,356	1,142
2008/09	1,422	1,219	1,426	1,150
2009/10	1,448	1,348	1,429	1,253
2010/11	1,413	1,354	1,428	1,279
2011/12	1,444	1,350	1,429	1,276
2012/13	1,499	1,420	1,504	1,339
2013/14	1,546	1,456	1,546	1,347
2014/15	1,553	1,266	1,554	1,217
2015/16	1,693	1,180	1,590	1,139
2016/17	1,659	1,050	1,578	1,015
2017/18	1,621	1,054	1,571	1,014
2018/19	1,865	1,184	1,830	1,135
2019/20	2,067	1,309	2,031	1,288
2020/21	1,735	1,358	1,733	1,267
2021/22	1,785	1,046	1,706	993
2022/23	1,654	824	1,585	784

Table 3: Timeseries of directed fishery total catch (t) computed using the status quo approach and the updated approach.

	Status Quo		Update	
Year	EAG	WAG	EAG	WAG
1990/91	3,981	3,982	3,521	2,695
1991/92	6,597	2,118	3,943	1,731
1992/93	5,436	1,039	5,054	1,289
1993/94		3,601	2,212	1,978
1994/95	3,444	5,054	3,974	5,191
1995/96	4,641	2,619	4,658	3,171
1996/97	2,563	1,972	3,207	2,290
1997/98	2,977	1,892	2,900	1,855
1998/99	3,141	1,107	2,949	1,590
1999/00	2,606	2,178	2,541	2,079
2000/01	2,760	2,273	2,592	2,313
2001/02	2,238	2,155	2,154	2,176
2002/03	1,916	1,900	1,871	1,889
2003/04	1,902	1,867	1,855	1,782
2004/05	1,695	1,886	1,671	1,839
2005/06	1,742	1,796	1,620	1,646
2006/07	1,647	1,551	1,617	1,400
2007/08	1,820	1,614	1,755	1,593
2008/09	1,824	1,733	1,774	1,697
2009/10	1,770	1,690	1,793	1,682
2010/11	1,757	1,605	1,702	1,602
2011/12	1,781	1,517	1,801	1,540
2012/13	1,947	1,839	1,946	1,778
2013/14	1,852	1,919	1,853	1,880
2014/15	1,967	1,592	1,965	1,584
2015/16	2,136	1,565	2,206	1,523
2016/17	2,234	1,570	2,214	1,493
2017/18	2,339	1,437	2,332	1,420
2018/19	2,735	1,637	2,778	1,639
2019/20	3,033	1,714	3,039	1,614
2020/21	2,608	1,844	2,604	1,763
2021/22	2,427	1,612	2,386	1,567
2022/23	2,210	1,097	2,078	1,122

Table 4: Status quo and updated timeseries of total catch (t) *cv* and number of observer sampled pots with non-zero catches (m_{nz}).

	Status Quo				Update			
	EAG		WAG		EAG		WAG	
Year	cv	m_{nz}	cv	m_{nz}	cv	m_{nz}	cv	m_{nz}
1990/91	0.359	138	0.208	340	0.284	130	0.222	220
1991/92	0.213	377	0.130	857	0.353	86	0.167	386
1992/93	0.296	199	0.145	690	0.340	92	0.235	196
1993/94			0.294	174	0.645	29	1.495	9
1994/95	0.375	127	0.107	1,270	0.528	41	0.110	877
1995/96	0.051	6,388	0.051	5,598	0.049	4,184	0.056	3,338
1996/97	0.045	8,360	0.045	7,194	0.045	5,043	0.045	5,282
1997/98	0.060	4,670	0.060	3,985	0.054	3,503	0.057	3,298
1998/99	0.068	3,616	0.088	1,876	0.059	2,939	0.078	1,747
1999/00	0.066	3,851	0.056	4,523	0.059	2,916	0.052	3,906
2000/01	0.058	5,043	0.055	4,740	0.048	4,432	0.051	4,035
2001/02	0.060	4,626	0.057	4,454	0.050	4,018	0.053	3,761
2002/03	0.065	3,980	0.076	2,509	0.054	3,472	0.070	2,181
2003/04	0.065	3,960	0.066	3,334	0.054	3,500	0.059	3,035
2004/05	0.087	2,206	0.074	2,619	0.072	1,955	0.067	2,374
2005/06	0.119	1,193	0.103	1,365	0.094	1,154	0.092	1,242
2006/07	0.124	1,098	0.111	1,183	0.097	1,073	0.098	1,116
2007/08	0.130	998	0.116	1,082	0.102	976	0.101	1,040
2008/09	0.166	613	0.122	979	0.130	606	0.106	943
2009/10	0.205	408	0.128	892	0.159	402	0.111	863
2010/11	0.198	436	0.129	867	0.155	425	0.114	816
2011/12	0.218	361	0.132	837	0.169	358	0.116	791
2012/13	0.197	438	0.114	1,109	0.153	437	0.100	1,066
2013/14	0.185	499	0.109	1,223	0.141	512	0.096	1,142
2014/15	0.213	376	0.113	1,137	0.166	370	0.102	1,025
2015/16	0.189	478	0.106	1,296	0.141	509	0.094	1,193
2016/17	0.166	617	0.117	1,060	0.124	658	0.105	967
2017/18	0.170	585	0.138	760	0.132	585	0.118	760
2018/19	0.189	475	0.145	688	0.141	513	0.124	688
2019/20	0.177	540	0.122	967	0.132	585	0.107	922
2020/21	0.173	567	0.113	1,137	0.134	565	0.097	1,137
2021/22	0.189	478	0.130	858	0.147	470	0.111	857
2022/23	0.226	336	0.134	805	0.175	336	0.115	800

Table 5: Status quo and updated timeseries of retained catch size composition stage 1 effective sample sizes ($\lambda_{Ret,i}$; i.e., number of vessel days or number of deliveries sampled).

	Status Quo		Update		N. Deliveries	
Year	EAG	WAG	EAG	WAG	EAG	WAG
1985	57	45	366	346	46	9
1986	11	23	221	348	29	11
1987	61	8	276	359	23	6
1988	352	286	498	368	238	509
1989	792	513	606	755	563	955
1990	163	205	213	342	251	473
1991	140	102	149	166	283	431
1992	49	76	104	104	301	326
1993	340	378	369	415	104	96
1994	319	367	777	734	156	173
1995	879	705	1,046	734	240	36
1996	547	817	615	957	79	229
1997	538	984	800	968	128	302
1998	541	613	605	525	79	245
1999	463	915	624	1,140	67	241
2000	436	1,029	545	1,099	109	190
2001	488	898	550	923	47	201
2002	406	628	497	695	55	169
2003	405	688	457	645	52	136
2004	280	449	333	453	36	124
2005	266	337	395	452	30	123
2006	234	337	297	312	19	126
2007	199	276	352	367	36	104
2008	197	318	310	391	20	103
2009	170	362	257	330	23	98
2010	183	328	272	305	23	96
2011	160	295	249	351	22	102
2012	187	288	277	406	25	62
2013	193	327	289	471	25	23
2014	168	305	200	531	21	30
2015	190	287	204	514	22	27
2016	247	408	271	459	26	24
2017	224	309	252	370	26	23
2018	256	291	255	361	27	21
2019	242	363	260	462	29	25
2020	227	462	286	502	29	27
2021	271	446	281	479	27	25
2022	238	341	238	341	21	18

Table 6: Status quo and updated timeseries of total catch size composition stage 1 effective sample sizes ($\lambda_{Tot,i}$; i.e., number of observed vessel days).

	Status Quo		Update	
Year	EAG	WAG	EAG	WAG
1990	22	190	67	239
1991	48	104	44	106
1992	41	94	44	85
1993		62	5	51
1994	34	119	121	237
1995	1,117	907	1,013	700
1996	509	1,061	615	957
1997	711	1,116	800	968
1998	574	638	605	525
1999	607	1,155	624	1,140
2000	495	1,205	545	1,099
2001	510	975	550	923
2002	438	675	497	695
2003	416	700	457	645
2004	299	488	333	453
2005	232	220	210	352
2006	143	321	194	250
2007	134	257	189	232
2008	113	258	148	242
2009	95	292	141	225
2010	108	222	172	211
2011	107	252	157	285
2012	99	241	143	322
2013	122	236	166	333
2014	99	219	108	353
2015	125	243	126	323
2016	155	253	176	280
2017	133	222	164	215
2018	234	318	141	237
2019	148	224	152	244
2020	155	302	158	305
2021	138	247	138	247
2022	90	226	90	226

Table 7: Timeseries of bycatch mortality (t) in groundfish fisheries computed using the status quo approach and accessed directly from AKFIN.

	Status Quo		Update	
Year	EAG	WAG	EAG	WAG
1989/90	0.83	0.10		
1990/91	2.59	0.57		
1991/92		0.03	0.04	
1992/93	1.23	0.44	0.13	0.00
1993/94	1.15		3.69	0.34
1994/95	0.36	0.12	1.31	0.10
1995/96	1.02	0.79	1.20	0.80
1996/97	0.27	2.60	0.36	4.67
1997/98	0.11	0.42	0.09	0.44
1998/99	1.06	1.88	0.90	0.58
1999/00	0.64	1.80	3.02	0.67
2000/01	1.13	1.09	1.68	0.43
2001/02	1.67	0.44	0.32	0.25
2002/03	2.39	1.28	21.43	0.76
2003/04	1.31	0.31	20.03	2.58
2004/05	0.30	1.01	0.81	0.73
2005/06	1.83	3.75	0.84	1.19
2006/07	3.31	2.37	21.29	1.15
2007/08	1.93	1.55	66.12	3.31
2008/09	4.30	9.30	29.19	7.48
2009/10	2.06	4.86	17.55	4.83
2010/11	6.27	2.66	49.31	3.25
2011/12	5.28	2.71	25.28	4.44
2012/13	6.17	4.34	9.46	6.48
2013/14	3.13	3.74	5.03	6.63
2014/15	2.86	2.66	9.45	4.99
2015/16	0.70	1.55	22.68	2.37
2016/17	2.07	2.36	95.48	3.98
2017/18	1.24	1.48	45.69	2.29
2018/19	1.25	1.36	23.76	3.40
2019/20	3.93	4.20	16.82	5.98
2020/21	0.73	0.81	125.42	6.40
2021/22	1.24	0.74	16.81	1.37
2022/23	2.15	1.57	7.23	3.53

Figures

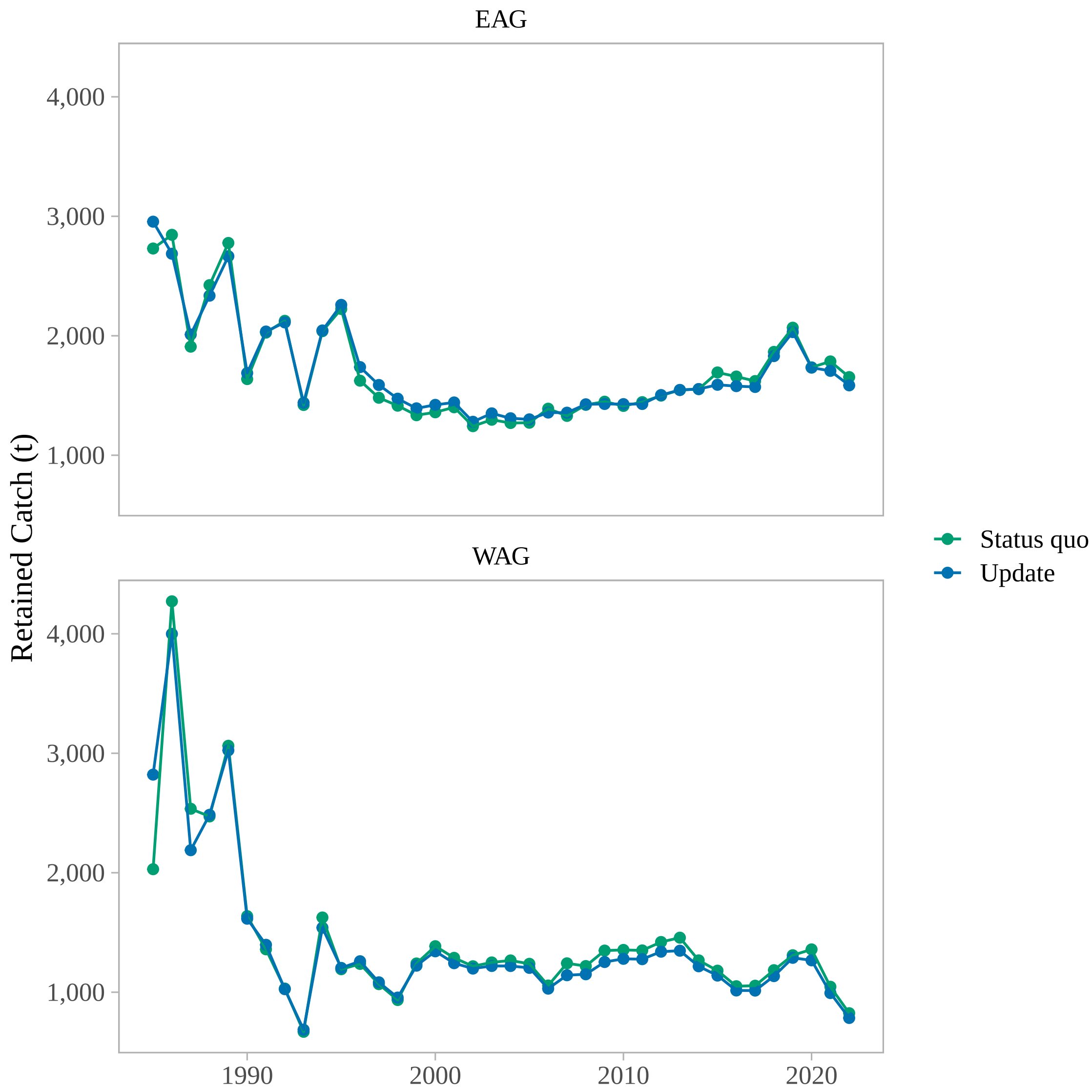

Figure 1: Timeseries of directed fishery retained catch (t) computed using the status quo approach and accessed directly from fish tickets.

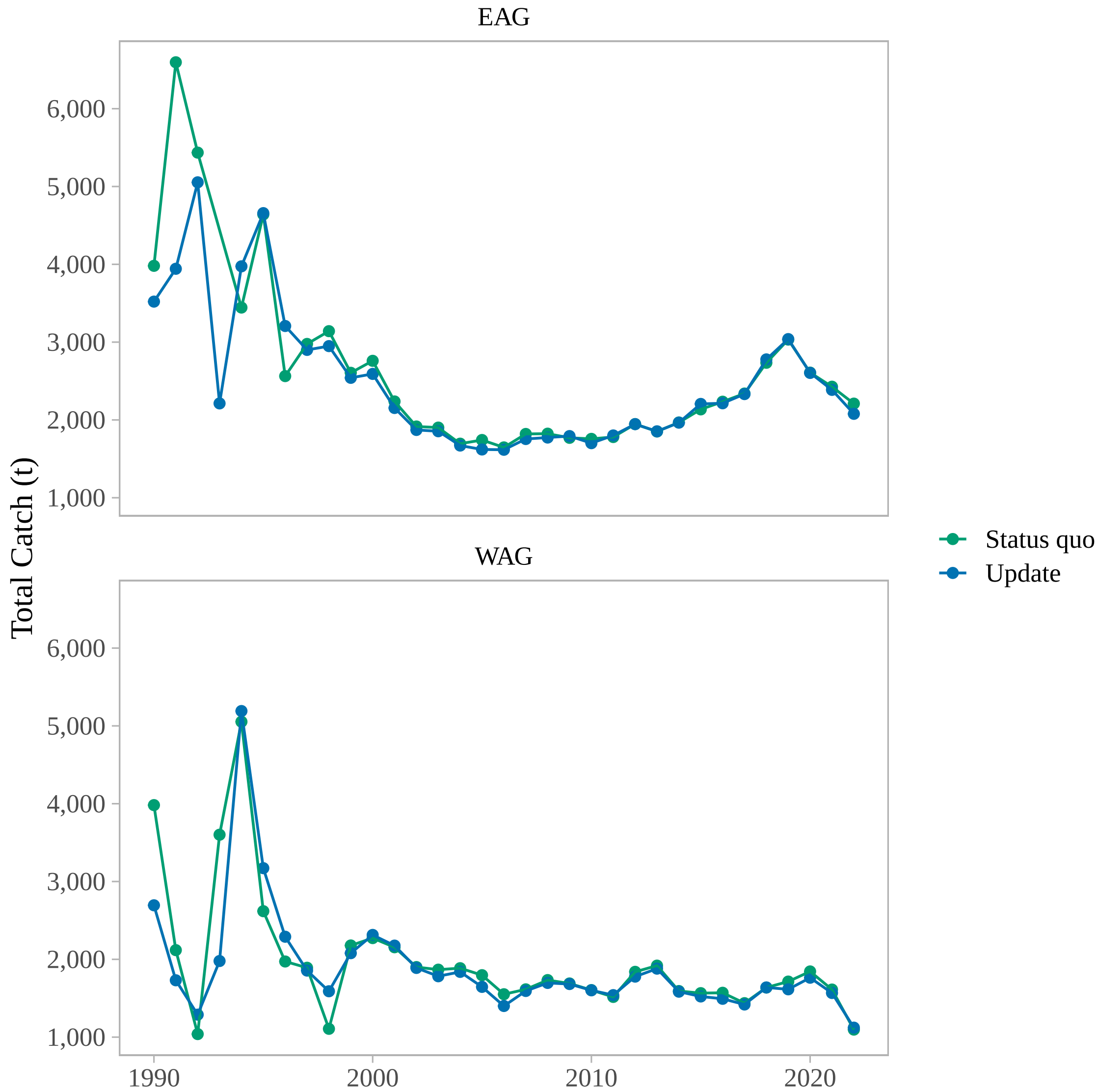

Figure 2: Timeseries of directed fishery total catch (t) computed using the status quo approach and the updated approach.

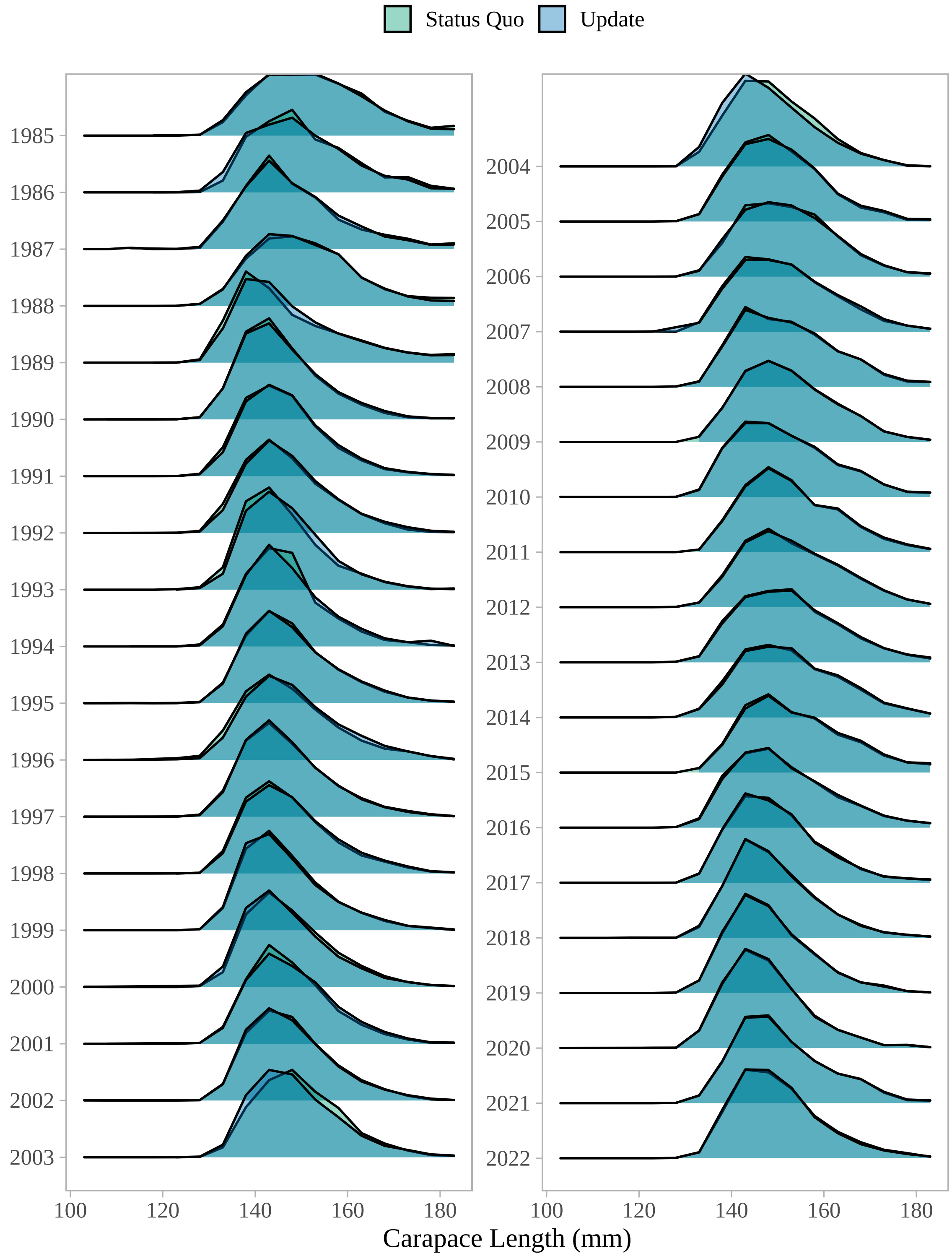

Figure 3: Timeseries of EAG retained catch size composition (expressed as proportion within year) computed using the status quo approach and the updated approach.

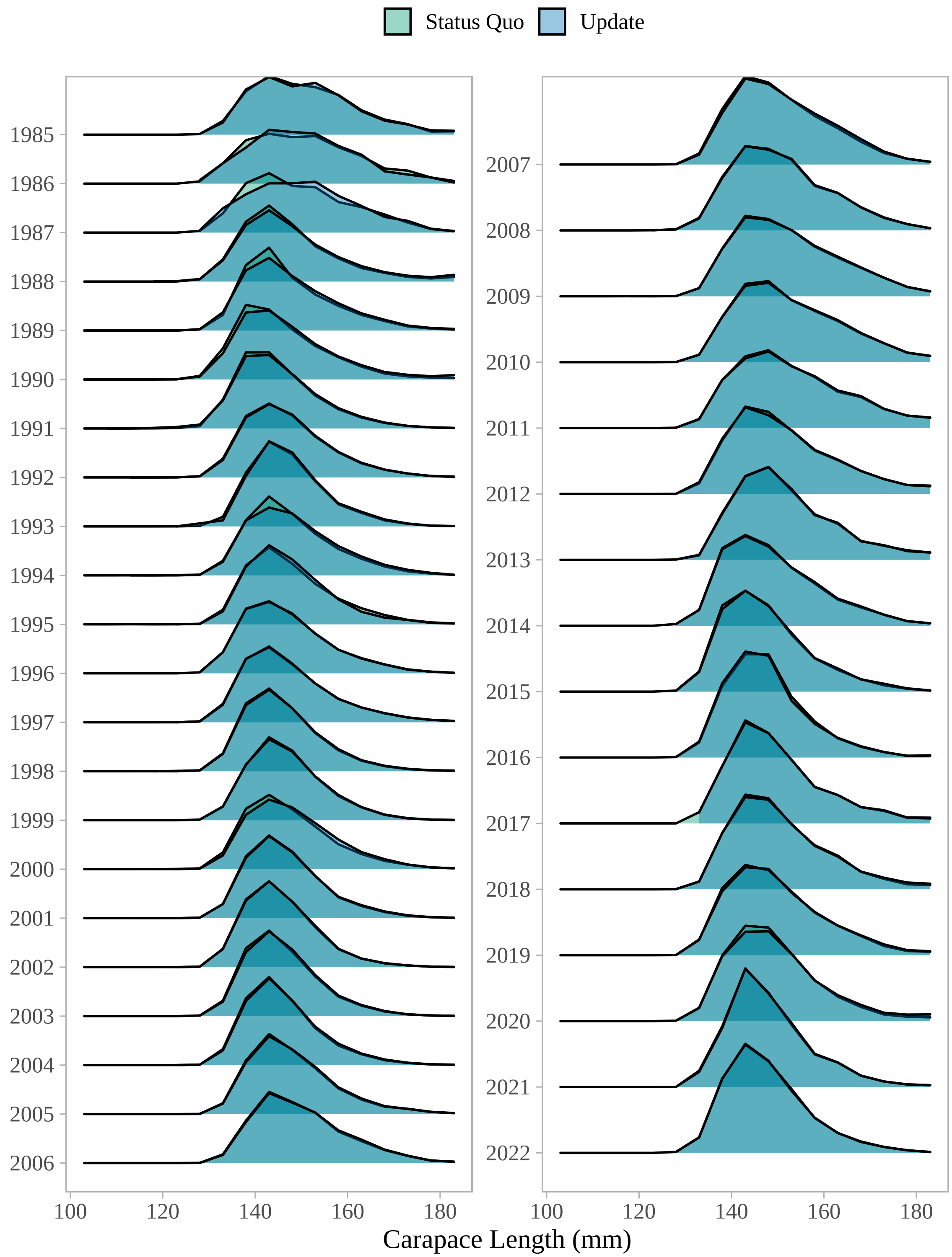

Figure 4: Timeseries of WAG retained catch size composition (expressed as proportion within year) computed using the status quo approach and the updated approach.

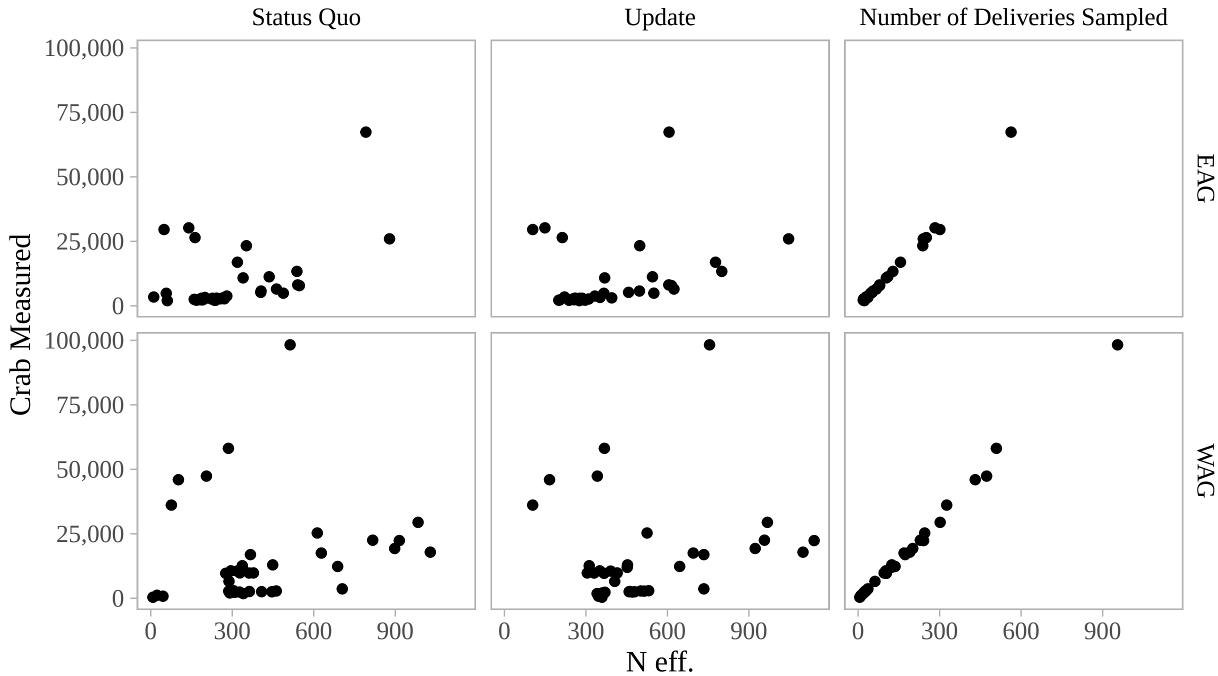

Figure 5: Relationship between retained catch effective sample size proxy and the number of crab measured.

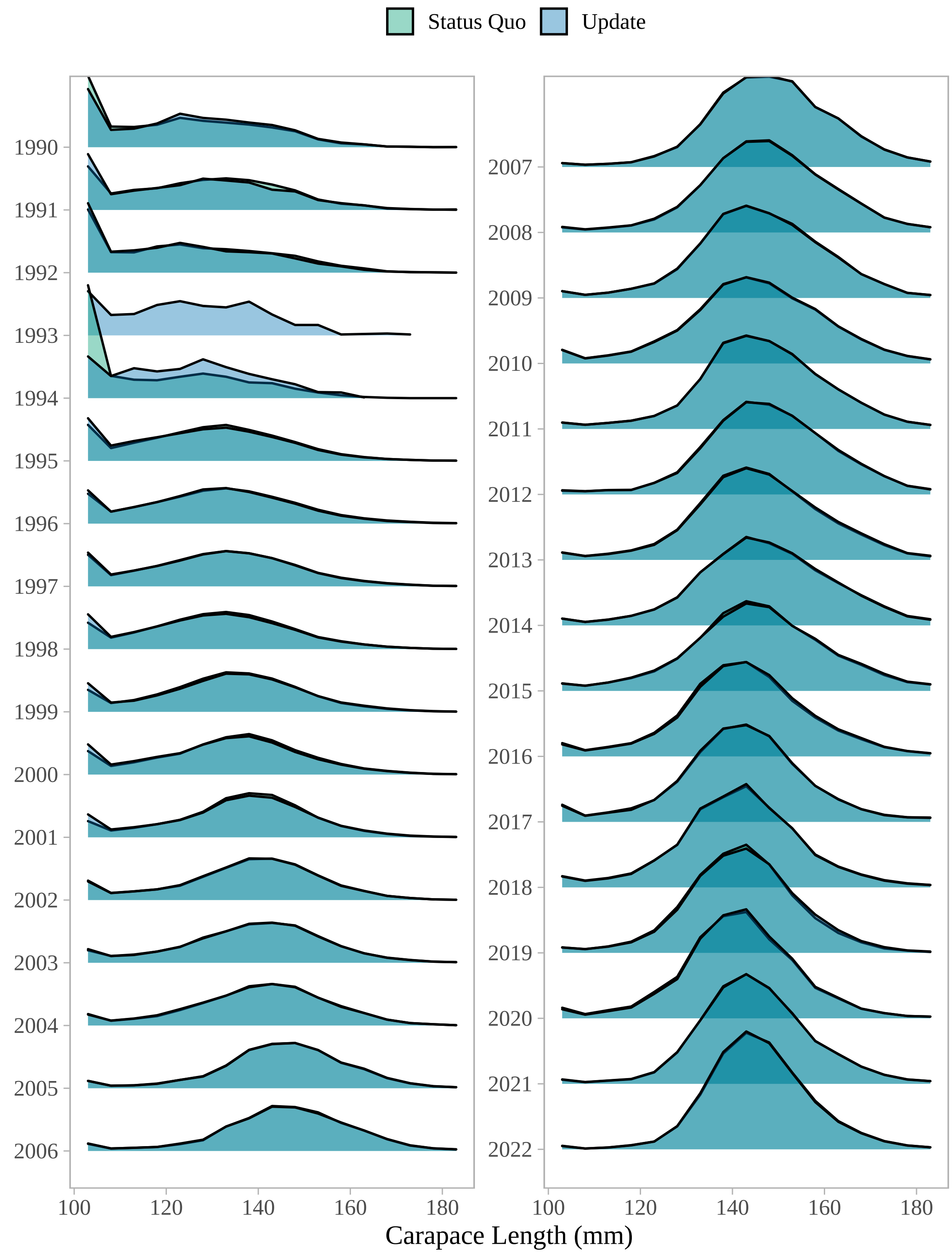

Figure 6: Timeseries of EAG total catch size composition (expressed as proportion within year) computed using the status quo approach and the updated approach.

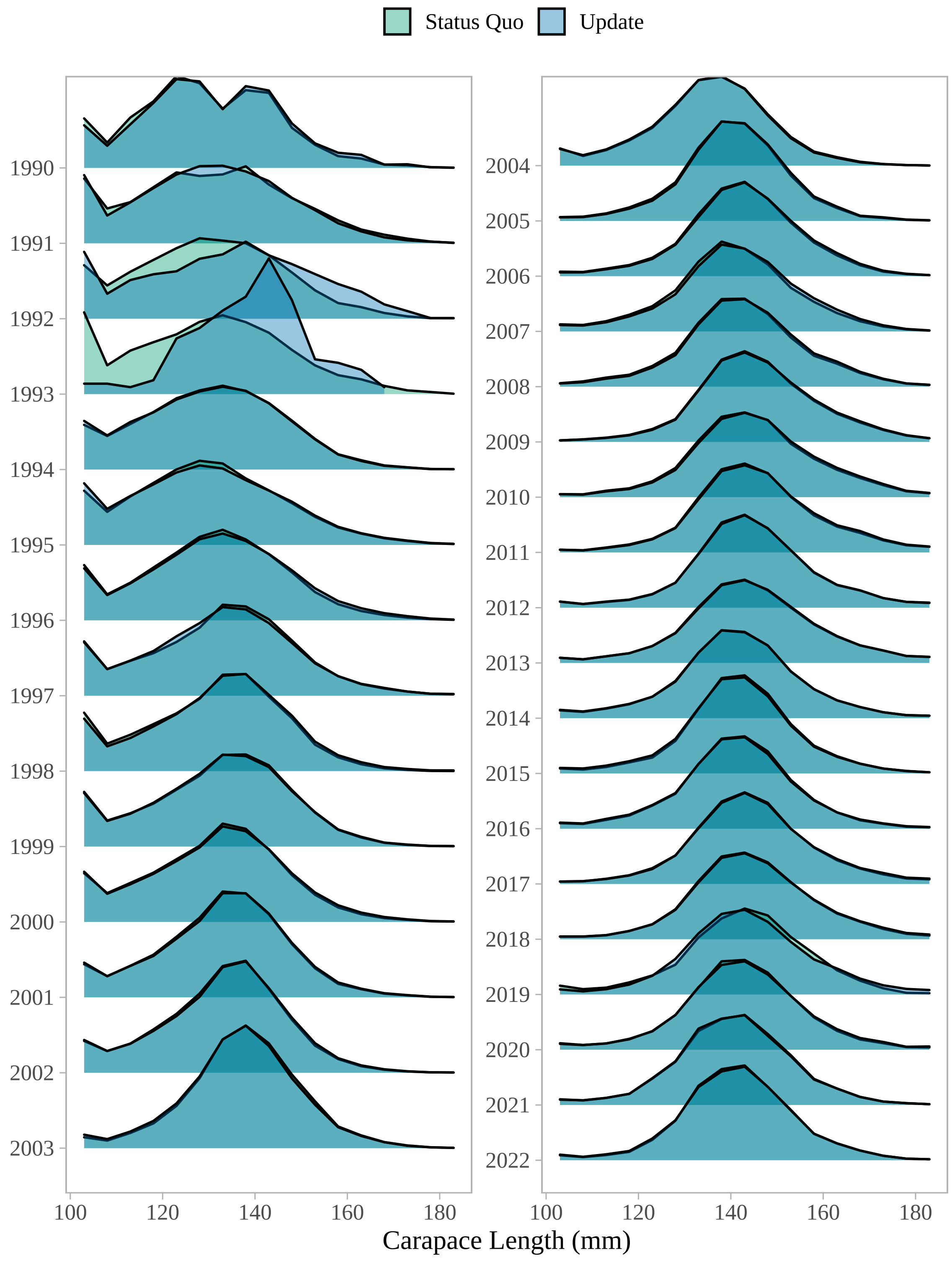

Figure 7: Timeseries of WAG total catch size composition (expressed as proportion within year) computed using the status quo approach and the updated approach.

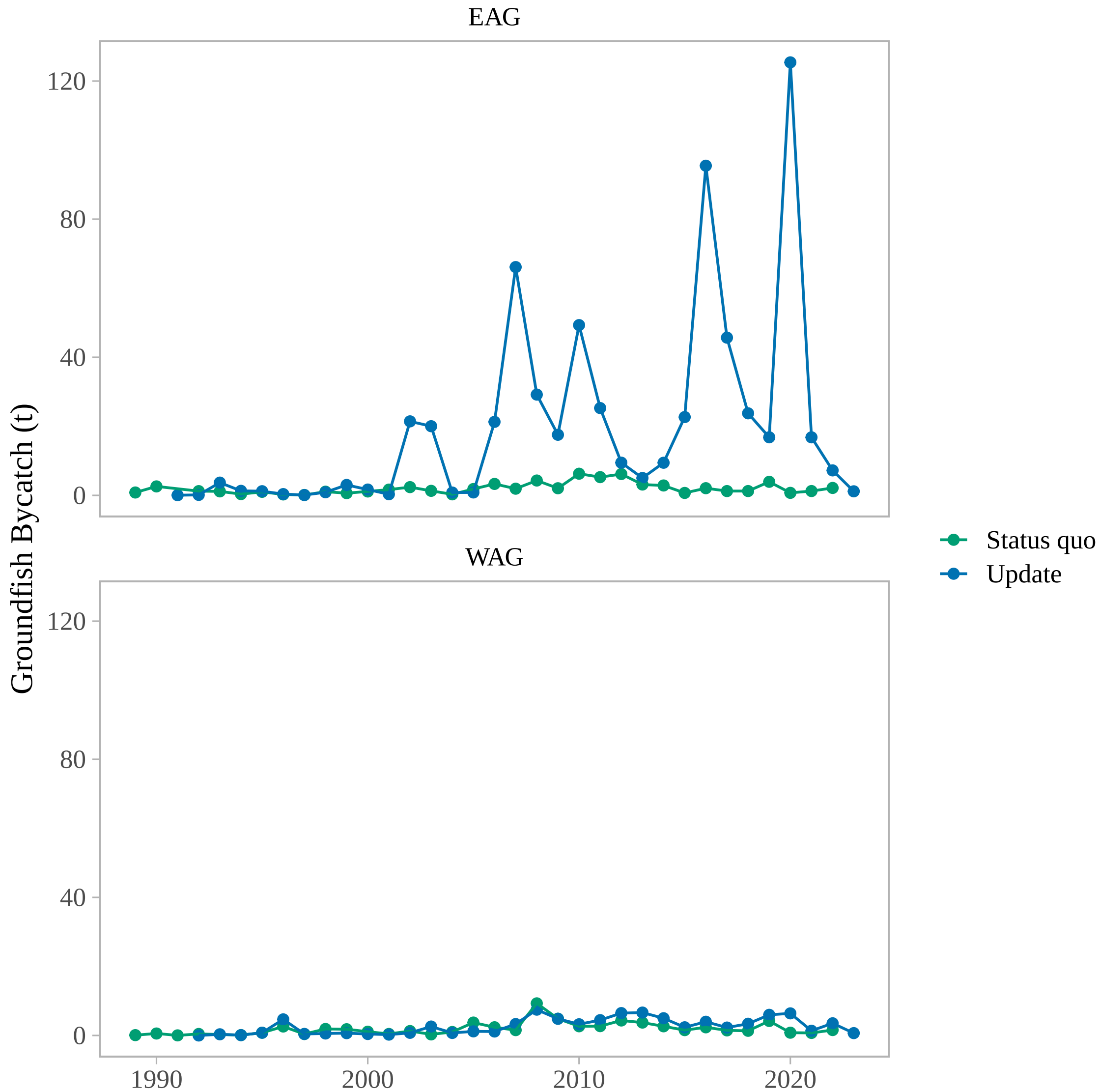

Figure 8: Timeseries of directed fishery groundfish bycatch (t) computed using the status quo approach and the updated approach.

Literature Cited

Cahalan, J.A., J.R. Gasper, and J. Mondragon, Jennifer. 2014. Catch sampling and estimation in the federal groundfish fisheries off Alaska, 2015 edition. NOAA technical memorandum NMFS-AFSC; 286. Alaska Fisheries Science Center, Seattle, WA.

Appendix B: AIGKC Fishery CPUE Standardization

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January 2024

Background

The AIGKC assessment has used catch per unit effort (CPUE) data collected by at-sea observers as a primary index of stock abundance since model development began (Siddeek et al. 2017 SAFE; Siddeek et al. 2016). The standardization method developed by Siddeek et al. (2016) used a negative binomial general linear model (GLM) with a hybrid model selection procedure in which variables are first selected by Akike Information Criterion, AIC (Burnham and Anderson 2002), and then model selection is repeated using an R^2 statistic representing the proportion of deviance explained. Explanatory variables,in addition to year, included pot soak time, sample month, vessel, vessel permit holder (i.e., proxy for captain), block (i.e., discrete geographic subarea, Figure 1), gear type, and depth. Soak time and depth were fit using cubic splines. Spline degrees of freedom and negative binomial dispersion parameter (θ) were estimated by calculating AIC for a range of values and locating the best value at the minimum AIC (see Siddeek et al, 2021 SAFE report). This appendix details proposed updates to the CPUE standardization procedure following improvements to the data management workflow and comments from the CPT.

Major Changes

Observer CPUE

Core Data Preparation

Siddeek et al. (2016, 2023) reduced the full observer data set to represent core fishing effort by limiting data to only vessels that made five deliveries during at least three seasons in the time series. Soak time and depth data were truncated by removing the outer 5% and 1% of distributions, respectively. Here, vessels were not limited by the number of deliveries made as that can be determined by vessel size, hold capacity, maintenance issues, quota share, GHL/TAC. Instead, core vessels and permit holders during the pre-rationalized time series were those that participated in more than a single season. The fleet was consolidated enough in the post-rationalized time series that reductions on number of vessels and permit holders were not warranted. Following Siddeek et al. (2016, 2023) several gear types were combined, and pot types not typical to the directed fishery were removed. Since many fishing seasons in the pre-rationalized era did not align with the crab year used in the post-rationalized era (July - June), crab year was assigned to pre-2005 data *post hoc*. Observer pots sampled on dates that fall after June 30 in a given season, were assigned the next crab year (Siddeek et al. 2016, 2023). Nominal CPUE computed from the core fishery data used in the current analysis is very similar to that previously used in CPUE standardization (Figure 2). A comparison of the sample size and number of factor levels between the current core data and that of Siddeek et al. (2023) is in Table 1.

Model Fitting

CPUE standardization models were fit using general additive models (GAM) as implemented in the R package *mgcv* (Wood 2004). All models assumed a negative binomial error distribution with log-link. Negative binomial overdispersion, θ, was estimated as a model parameter. All splines were fit as thin plate regression splines, with smoothness determined by generalized cross-validation (Wood 2004).

Dependent Variable

Siddeek et al. (2016, 2023) developed a standardized CPUE index of only legal males, and the stock assessment fits to relative abundance of only legal males accordingly. Here an index of total male CPUE was also developed for comparison. Total male CPUE was only modeled as a negative binomial GAM without a year:block interaction.

Variable Selection

Null models included only crab year as an explanatory variable

$$\ln(CPUE_i) = Year_{y,i} \tag{1}$$

or an interaction between year and block

$$\ln(CPUE_i) = Year_{y,i} : Block_{b,i} \tag{2}$$

The full scope of models evaluated included gear (i.e., pot size), vessel, permit holder, month and block as factorial variables. Prospective smoothed terms include soak time, depth, slope angle, and the interaction of latitude and longitude. Sea floor slope angle (degrees) was computed in ArcGIS (Redlands, 2011) from a 100-m resolution raster surface of Aleutian Islands bathymetry (Zimmermann 2013). Evaluating block and the two-dimensional smooth of latitude and longitude allows the model to fit location data at different scales and selection of a 'best' model would not include both variables. If the best model included latitude and longitude, the tensor interaction of latitude and longitude was also evaluated.

Siddeek et al. (2016, 2023) used stepwise model selection based on AIC implemented by the stepAIC function of the R library $MASS$ (Venables and Ripley 2002). The best model was then further refined using a modified version of the stepAIC function in which proportion of deviance explained (R^2) was used as selection criteria. Addition of new variables were considered significant if AIC decreased by at least two per degree of freedom lost and R^2 increased by at least 0.01. In this analysis, AIC and R^2 were used as selection criteria in a single step. Variables were added (or subtracted) from the model until no candidate variables met AIC and R^2 criteria. Consistent AIC (CAIC; -2LogLik+(ln(n)+1)p; Bozdogan 1987) was used instead of the traditional AIC, in which n is the number of observations and p is the number of parameters (Siddeek et al. 2016, 2023).

$$\mathrm{R}^2 = \frac{D_{Null} - D_{Resid}}{D_{Null}} \tag{3}$$

Fish Ticket CPUE

Fish ticket CPUE from 1985 - 1998 was standardized using a negative binomial linear model and the same model selection criteria as Siddeek et al. (2023). Here, statistical area was evaluated as an explanatory variable opposed to block, to avoid the need for joining fish ticket data to observer pot locations. Core data were selected by limited vessels and permit holders that were present in more than five seasons. Sample size by year is listed in Table 3.

CPUE index

Following Siddeek et al. (2016, 2023) standardized CPUE index was extracted from the models as the year coefficient (β_i) with the first level set to zero and scaled to canonical coefficients (β_i') as

$$\beta_i' = \frac{\beta_i}{\bar{\beta}} \tag{4}$$

where

$$\bar{\beta} = \sqrt[n_j]{\prod_{j=1}^{n_j} \beta_{i,j}} \tag{5}$$

and n_j is the number of levels in the year variable. Nominal CPUE was scaled by the same method for comparison. For models that included a year-block interaction, β_i was the weighted mean of year coefficients for each block with area of each block that has ever been fished (nmi^2) as the weight (Table 2). For models that included

$$lat \otimes lon$$

by year, β_i was mean fitted for each year based on a prediction set of data consisting of each factor level and the mean value of smoothed terms.

Results

Legal CPUE

Nearly all models selected gear type and permit holder as parametric effects. Only the year:block model for the EAG and WAG post-rationalized period did not select permit holder, though the Vessel was selected for the EAG. Soak time was selected for all models except the year:block model for the post-rationalized period in the EAG, and both the post-rationalized year and year:block models in the WAG (Tables 4 - 11). Estimated degrees of freedom (EDF) for soak time ranged from 4.67-5.12 in the EAG which resulted in an asymptotic increase, whereas EDF ranged from 7.83-7.97 in the pre-rationalized WAG which yielded a wiggly increasing trend (Tables 4 - 6, 8-9; Figures 4-10, 16-19). A two-dimensional smoothing spline on latitude and longitude was selected for the pre-rationalized period in the EAG (EDF = 26.72) and both time periods in the WAG (pre EDF = 26.08, post EDF = 26.98) (Tables 4, 8, & 10; Figures 5, 5, & 23). The tensor interaction of latitude and longitude improved these models based on R^2 criteria, but not AIC. Month and Vessel were selected by only the EAG and pre- and post-rationalized models, respectively (Tables 4 & 6; Figures 4 & 10).

Diagnostic plots of residuals highlighted an excess of zero observations all models, though less so for the EAG pre-rationalized period (Figures 3, 6, 9, 11, 15, 18, 21, & 24). Additional work should revisit two-stage models that model zero catches and positive catches separately. Siddeek et al. (2016) noted that delta-lognormal models did not perform as well a negative binomial models, though hurdle-GAMs that assume a zero-truncated negative binomial distribution for positive catches could also be explored. Further, residual patterns associated with excess zeros may be resolved by evaluating mixed-effect models.

The resulting standardized indices follow a similar trend to nominal CPUE and the previous GLM based index (Figures 14 & 27). In the pre-rationalized EAG, GLM and GAM based indices are more stationary until 2005, whereas the GAM year:block and nominal indices closely mirror each other and increase throughout the time series (Figure 14). GAM derived indices without year:block should be used by the assessment model based on model performance and diagnostics. Models including year:block did not improve deviance explained, except for the post-rationalization period in the WAG (Tables 4 - 11). Though, pots in block ten were removed because it was only fished in two years of the time series and data were limited to there being at least ten pots fished in each combination of year, block, gear type, vessel, and permit holder. Using all data resulted in model evaluations with undefined null deviance.

Total Male CPUE

Pre-rationalized models selected gear type, permit holder, and s(longitude, latitude) in the EAG and WAG, with the WAG model also selecting vessel (Tables 12-15; Figures 29-39). EAG and WAG estimated 28.42 and 28.51 degrees of freedom for s(longitude, latitude), respectively, similar to legal CPUE models. Post-rationalized model selection differed between areas. Month, Vessel, and s(longitude, latitude, EDF = 26.5) were selected for the EAG while permit holder and s(longitude, latitude, EDF = 27.9) were selected for the

WAG. Overdispersion (θ) was similar between total and legal CPUE models during each area and period, and residual patterns remained largely unchanged (Figures 28, 31, 34, & 37). Total CPUE and Legal CPUE indices follow the same trends in most years, though the scale of indices varies (Figures 42 - 43). Differences between indices are most apparent in the pre-rationalized period, as well as 2007-2008 in the WAG.

Fish Ticket CPUE

Both EAG and WAG models selected only vessel as an explanatory variable in addition to year (Table 16 - 17). Model diagnostics indicated obvious residual patterns in both subdistricts, which should be further investigated (Figures 44 and 46). Resulting indices slightly differ from the status quo standardized index, particular 1998 in the EAG (Figure 45) and 1985 in the WAG (Figure 47).

Tables

Table 1: Comparison on total sample size and number of levels for each factor covariate between core data sets of Siddeek et al. (2023) and the current analysis by time period and subdistrict.

		EAG		WAG	
Core Data	Factor	Pre-	Post-	Pre-	Post-
Siddeek et al. (2023)	N	31,636	9,271	32,527	16,504
	Permit Holder	48	15	55	16
	Vessel	20	8	19	7
	Gear Type	7	4	7	7
	Block	4	4	6	6
	Month	12	8	12	10
Current Analysis	N	31,057	9,769	29,895	16,978
	Permit Holder	32	15	33	17
	Vessel	20	8	17	7
	Gear	7	4	7	7
	Block	4	4	6	6
	Month	12	8	12	10

Table 2: Number of 1 nmi x 1 nmi cells ever fished (area) with each block.

Block	Area (nmi^2)
1	375
2	1,364
3	1,765
4	915
5	452
6	1,026
7	812
8	2,172
9	1,042
10	334

Table 3: Number of factor levels by variable, year, and subdistrict for core fish ticket data from 1985 - 1998.

	EAG				WAG			
Year	Vessel	Permit Holder	Month	Stat Area	Vessel	Permit Holder	Month	Stat Area
1985	7	4	12	12	14	2	9	30
1986	8	5	10	13	12	7	10	31
1987	8	10	11	10	8	9	9	15
1988	9	14	12	19	9	11	10	32
1989	9	14	12	21	10	14	10	45
1990	10	14	12	18	8	10	10	28
1991	10	12	11	21	7	7	10	21
1992	6	11	11	18	6	7	9	25
1993	7	10	12	20	11	11	9	22
1994	8	12	12	20	9	12	10	40
1995	9	10	11	23	9	12	8	42
1996	8	11	6	24	11	14	11	46
1997	8	8	3	25	5	6	12	56
1998	8	8	3	18	4	7	12	47

Table 4: Residual degrees of freedom, AIC, and R^2 for the EAG pre-rationalized period best legal CPUE model including year (Yr), gear type (Gr), permit holder (PH), month (Mon), s(soak time), and s(longitude, latitude).

Form ($\theta = 1.4$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr + Gr + PH + Mon + s(soak time, 5.03) + s(lon, lat, 26.72)	30,967.25	203,712	0.23
+ Vessel	-10.97	-83.21	0.005
+ s(depth)	-6.04	29.11	0.001
+ s(slope)	-2.65	-42.53	0.002

Table 5: Residual degrees of freedom, AIC, and R^2 for the EAG pre-rationalized period best year:block, legal CPUE model including year:block (Yr:B), gear type (Gr), permit holder (PH), and s(soak time).

Form ($\theta = 1.385$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr:B + Gr + PH + s(soak time, 4.67)	30,976.33	203,867	0.22
+ Month	-11.09	-211.60	0.008
+ Vessel	-11.03	-0.48	0.003
+ s(depth)	-5.59	28.34	0.001
+ s(slope)	-0.98	-31.91	0.001

Table 6: Residual degrees of freedom, AIC, and R^2 for the EAG post-rationalized period best legal CPUE model including year (Yr), gear type (Gr), permit holder (PH), and s(soak time).

Form ($\theta = 2.321$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr + Gr + PH + s(soak time, 5.12)	9,728.88	85,976	0.12
+ Month	-6.87	-7.23	0.006
+ Vessel	-3.14	27.45	0.000
+ s(depth)	-3.09	21.51	0.001
+ s(slope)	-2.04	9.92	0.002
+ s(longitude,latitude)	-22.46	135.20	0.008

Table 7: Residual degrees of freedom, AIC, and R^2 for the EAG post-rationalized period best year:block, legal CPUE model including year:block (Yr:B), gear type (Gr), and Vessel (Ves).

Form ($\theta = 2.338$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr:B + Gr + Ves	9,695	86,123	0.12
+ s(soak time)	-5.20	-46.66	0.008
+ Month	-7.00	-22.66	0.008
+ Permit Holder	-10.00	35.65	0.005
+ s(depth)	-2.77	20.47	0.001
+ s(slope)	-2.26	-1.23	0.002

Table 8: Residual degrees of freedom, AIC, and R^2 for the WAG pre-rationalized period best legal CPUE model including year (Yr), gear type (Gr), permit holder (PH), s(soak time), and s(longitude, latitude).

Form ($\theta = 0.97$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr + Gr + PH + s(soak time, 7.97) + s(lon, lat, 26.08)	29,812.95	179,942	0.15
+ Month	-10.21	-124.30	0.006
+ Vessel	-6.54	-102.10	0.005
+ s(depth)	-7.07	-19.12	0.003
+ s(slope)	-3.02	41.83	0.000

Table 9: Residual degrees of freedom, AIC, and R^2 for the WAG pre-rationalized period best year:block, legal CPUE model including year:block (Yr:B), gear type (Gr), permit holder (PH), and s(soak time).

Form ($\theta = 0.972$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr:B + Gr + PH + s(soak time, 7.83)	29,792.17	180,116	0.15
+ Month	-10.19	-174.89	0.008
+ s(depth)	-6.82	-31.10	0.003
+ s(slope)	-2.34	25.76	0.000

Table 10: Residual degrees of freedom, AIC, and R^2 for the WAG post-rationalized period best legal CPUE model including year (Yr), gear type (Gr), permit holder (PH), and s(longitude, latitude).

Form ($\theta = 1.109$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr + Gr + PH + s(lon, lat, 27)	16,911.02	134,244	0.09
+ s(soak time)	-7.29	-70.58	0.007
+ Month	-9.01	-89.86	0.009
+ Vessel	-2.15	-46.39	0.003
+ s(depth)	-2.55	-3.14	0.002
+ s(slope)	-1.53	23.94	0.000

Table 11: Residual degrees of freedom, AIC, and R^2 for the WAG post-rationalized period best year:block, legal CPUE model including year:block (Yr:B) and gear type (Gr).

Form ($\theta = 1.102$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr:B + Gr	15,905	180,116	0.15
+ s(soak time)	-7.49	-62.46	0.007
+ Month	-9.00	-88.48	0.008
+ Vessel	-6.00	-68.81	0.006
+ Permit Holder	-16.00	-5.55	0.008
+ s(depth)	-2.85	-40.88	0.003
+ s(slope)	-1.99	-4.45	0.001

Table 12: Residual degrees of freedom, AIC, and R^2 for the EAG pre-rationalized period best total male CPUE model including year (Yr), gear type (Gr), permit holder (PH), and s(longitude, latitude).

Form ($\theta = 1.243$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr + Gr + PH + s(lon, lat)	30,980.58	250,363	0.22
+ s(soak time)	-5.08	-69.76	0.003
+ Month	-10.96	38.38	0.002
+ Vessel	-10.93	24.01	0.002
+ s(depth)	-6.53	-147.33	0.005
+ s(slope)	-2.30	-32.10	0.002

Table 13: Residual degrees of freedom, AIC, and R^2 for the EAG post-rationalized period best total male CPUE model including year (Yr), month (Mon), Vessel (Ves), and s(longitude, latitude).

Form ($\theta = 2.109$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr + Mon + Ves + s(lon, lat)	30,980.58	250,363	0.22
+ s(soak time)	-4.88	3.89	0.004
+ Month	-7.13	-21.45	0.007
+ Vessel	-3.06	9.86	0.002
+ Gear	-2.65	-82.59	0.009
+ s(depth)	-3.09	8.07	0.003
+ s(slope)	-2.22	-6.61	0.003

Table 14: Residual degrees of freedom, AIC, and R^2 for the WAG pre-rationalized period best total male CPUE model including year (Yr), gear type (Gr), permit holder (PH), Vessel (Ves), and s(longitude, latitude).

Form ($\theta = 0.838$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (Δ R^2)
Yr + Gr + PH + Ves + s(lon, lat)	29,811.49	224,733	0.19
+ s(soak time)	-7.66	-202.91	0.007
+ Month	-11.00	39.90	0.002
+ s(depth)	-7.00	-160.88	0.006
+ s(slope)	-1.00	-17.71	0.001

Table 15: Residual degrees of freedom, AIC, and R^2 for the WAG post-rationalized period best total male CPUE model including year (Yr), permit holder (PH), and s(longitude, latitude).

Form ($\theta = 1.04$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr + PH + s(lon, lat)	16,916.12	145,659	0.13
+ s(soak time)	-7.38	2.85	0.003
+ Month	-9.05	-58.69	0.007
+ Vessel	-2.10	-33.43	0.002
+ Gear	-5.87	-184.90	
+ s(depth)	-2.24	27.46	0.000
+ s(slope)	-0.96	10.84	-0.000

Table 16: Residual degrees of freedom, AIC, and R^2 for the best model fit to fish ticket data from the EAG 1985 - 1998.

Form ($\theta = 0.557$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr + Vessel	1,985	10,993	0.079
+ Permit Holder	-19	-2	
+ Month	-11	65	
+ Stat Area	-38	251	

Table 17: Residual degrees of freedom, AIC, and R^2 for the best model fit to fish ticket data from the WAG 1985 - 1998.

Form ($\theta = 0.88$)	Residual DF (Δ DF)	AIC (Δ AIC)	R^2 (ΔR^2)
Yr + Vessel	3,323	19,775	0.152
+ Permit Holder	-9	55	
+ Month	-11	31	
+ Stat Area	-88	705	

Figures

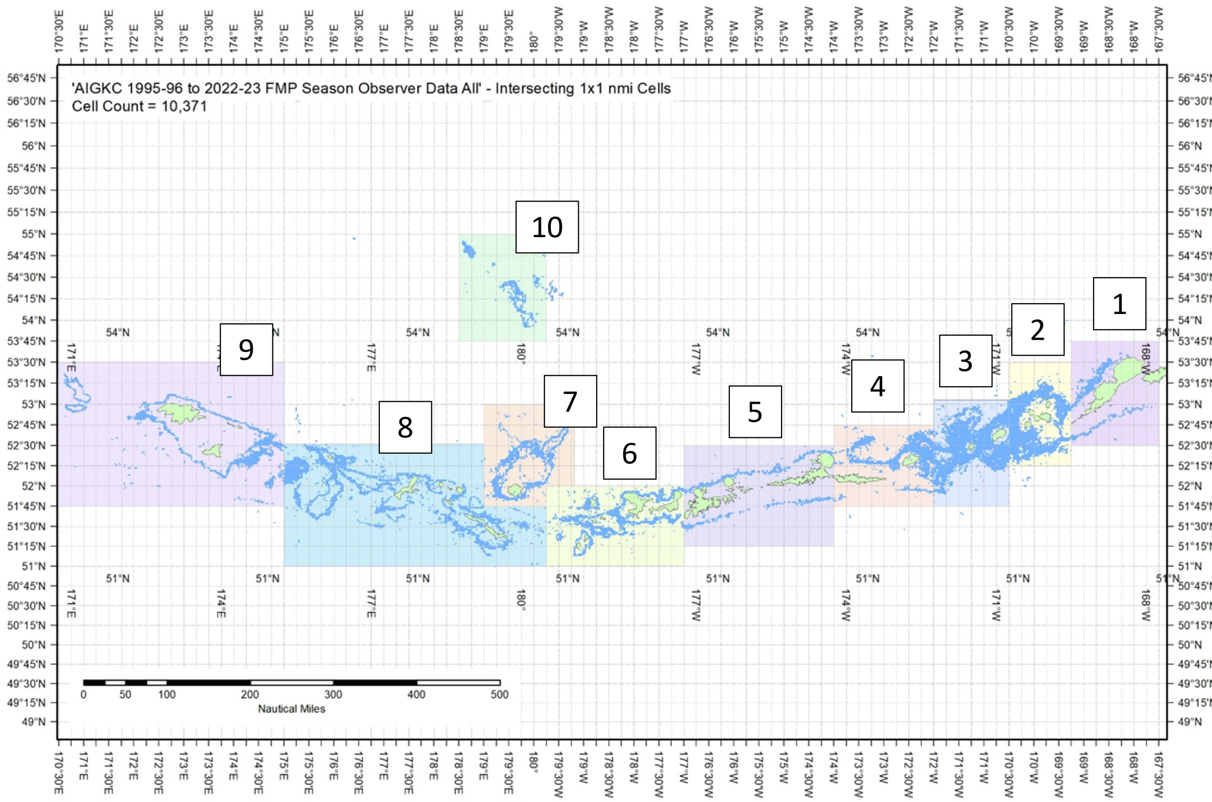

Figure 1: The 1995/96-2022/23 AIGKC observer pot samples enmeshed in 10 blocks.

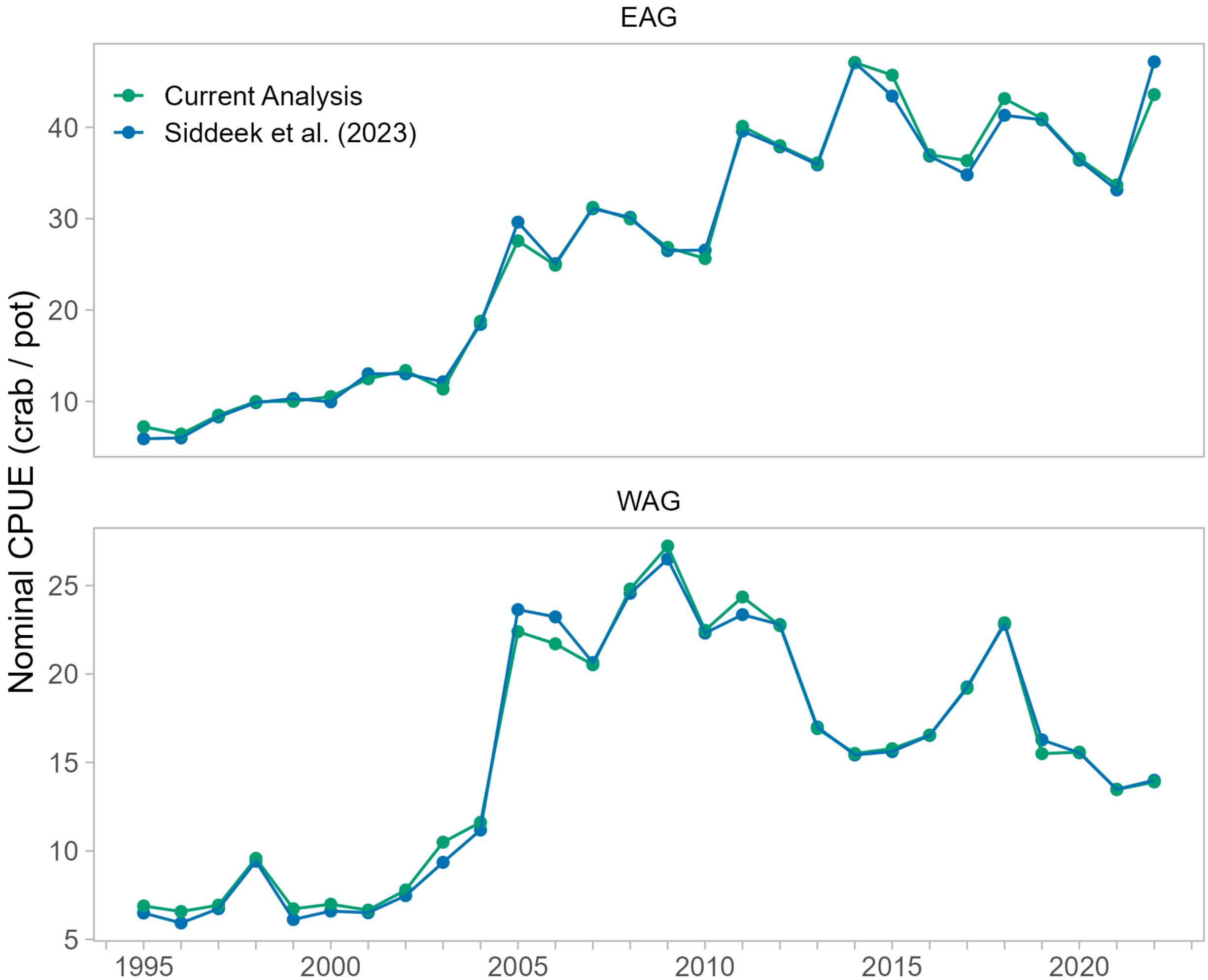

Figure 2: Annual nominal CPUE (crab / pot) computed using core data from the current analysis and that used by Siddeek et al. (2023).

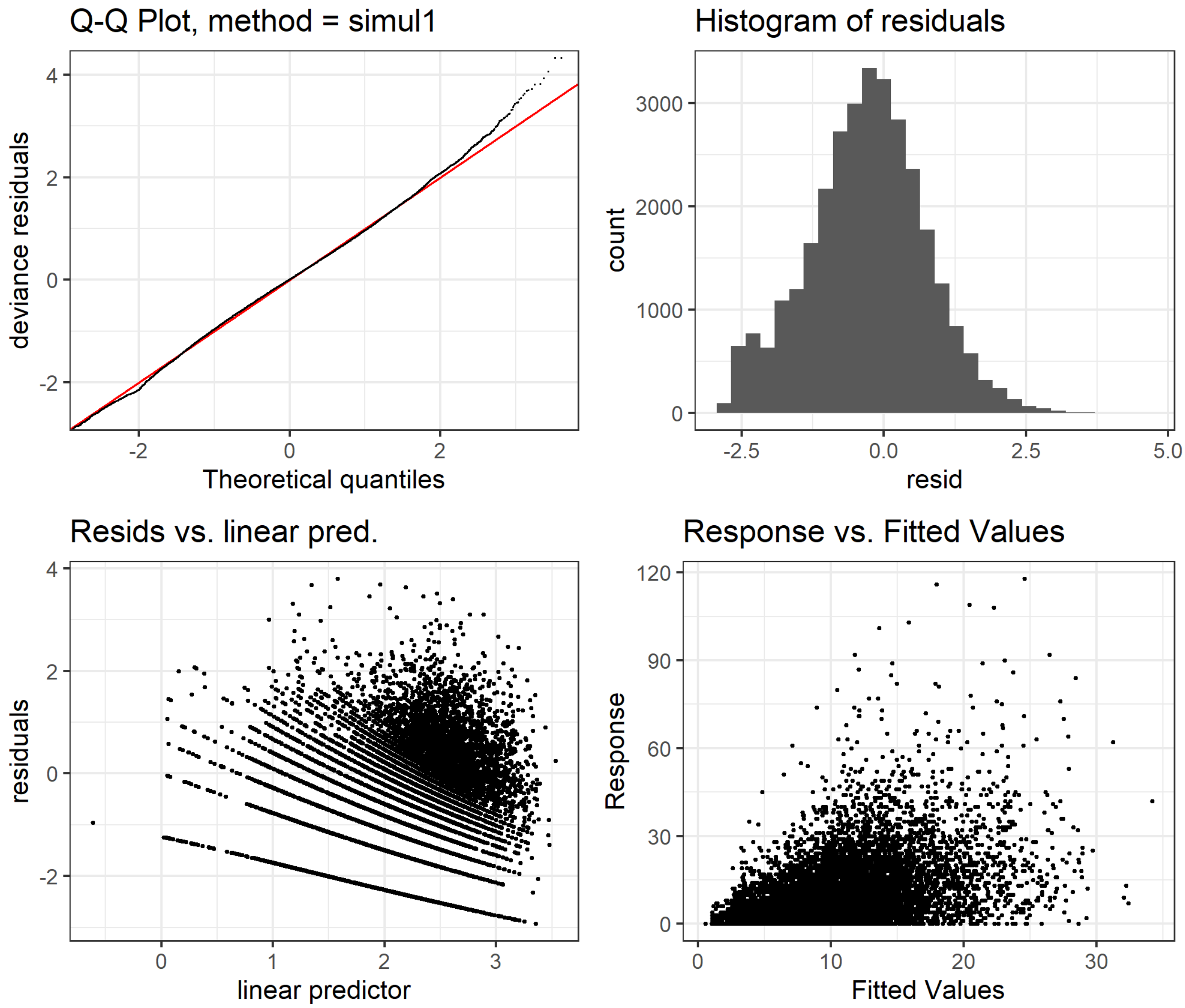

Figure 3: Diagnostic plots for the final GAM fit to legal CPUE during the pre-rationalized period in the EAG.

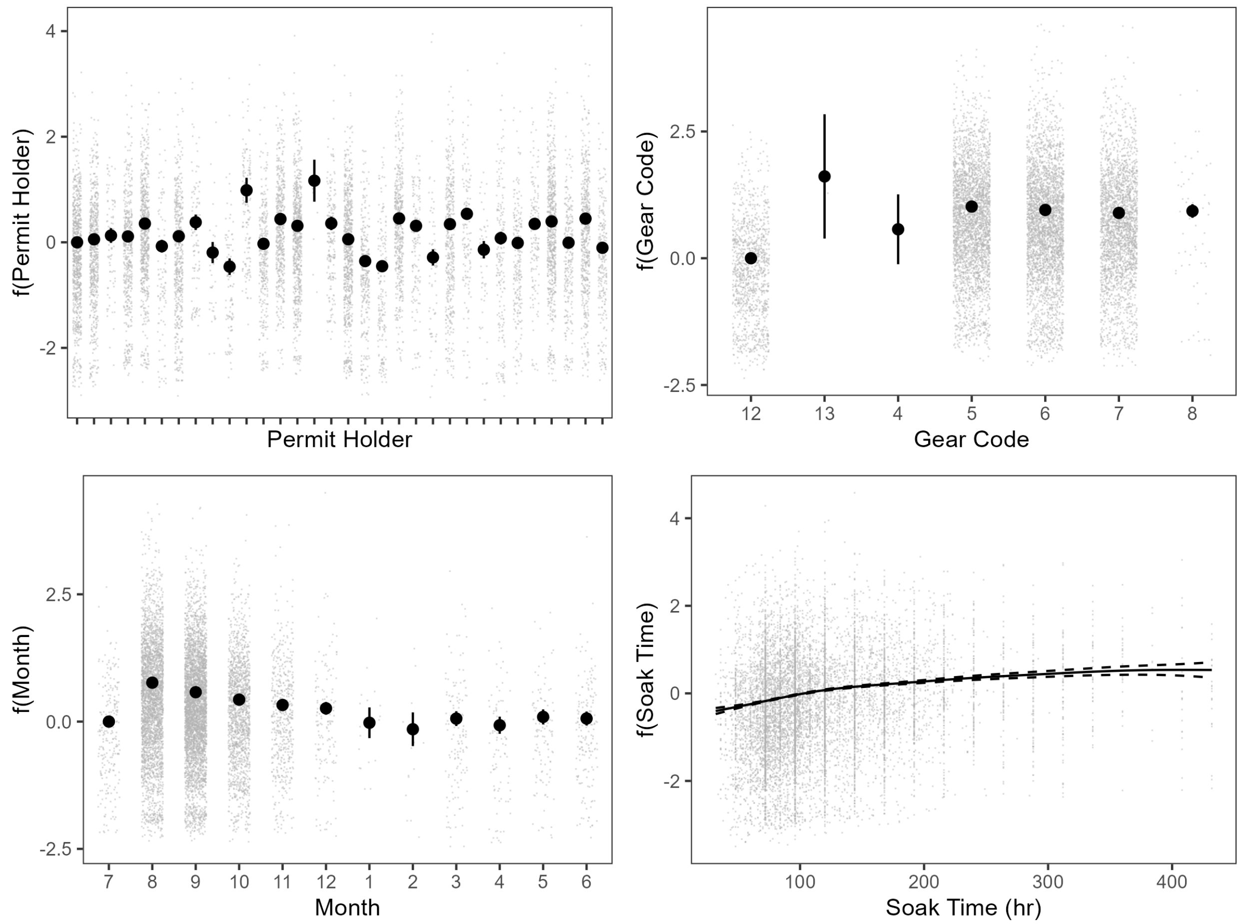

Figure 4: Marginal effects of permit holder, gear type, and soak time with associated partial residuals for the final model fit to legal CPUE during pre-rationalized period in the EAG.

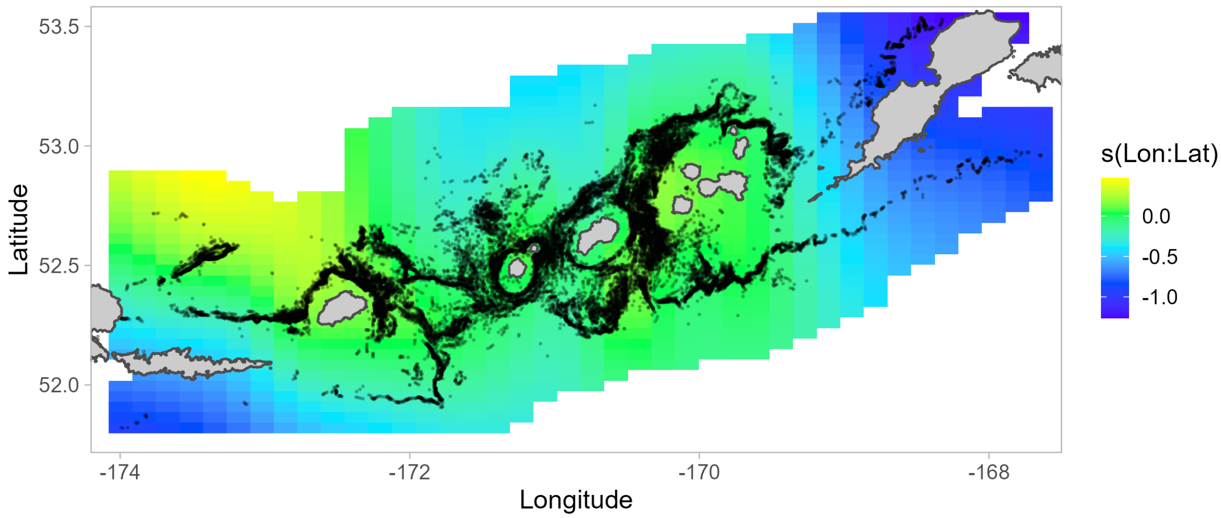

Figure 5: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to legal CPUE during pre-rationalized period in the EAG.

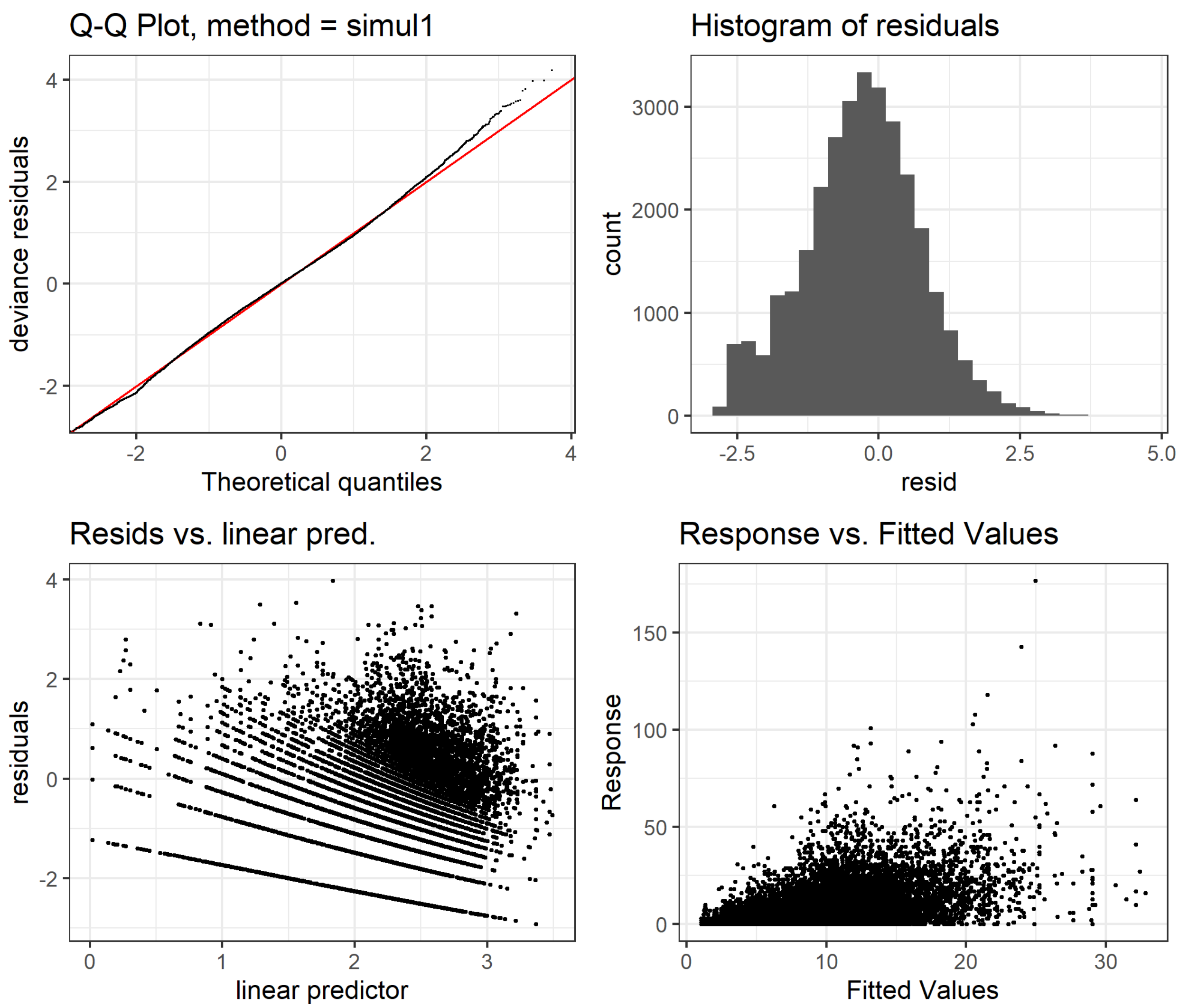

Figure 6: Diagnostic plots for the final GAM including year:block, fit to legal CPUE during the pre-rationalized period in the EAG.

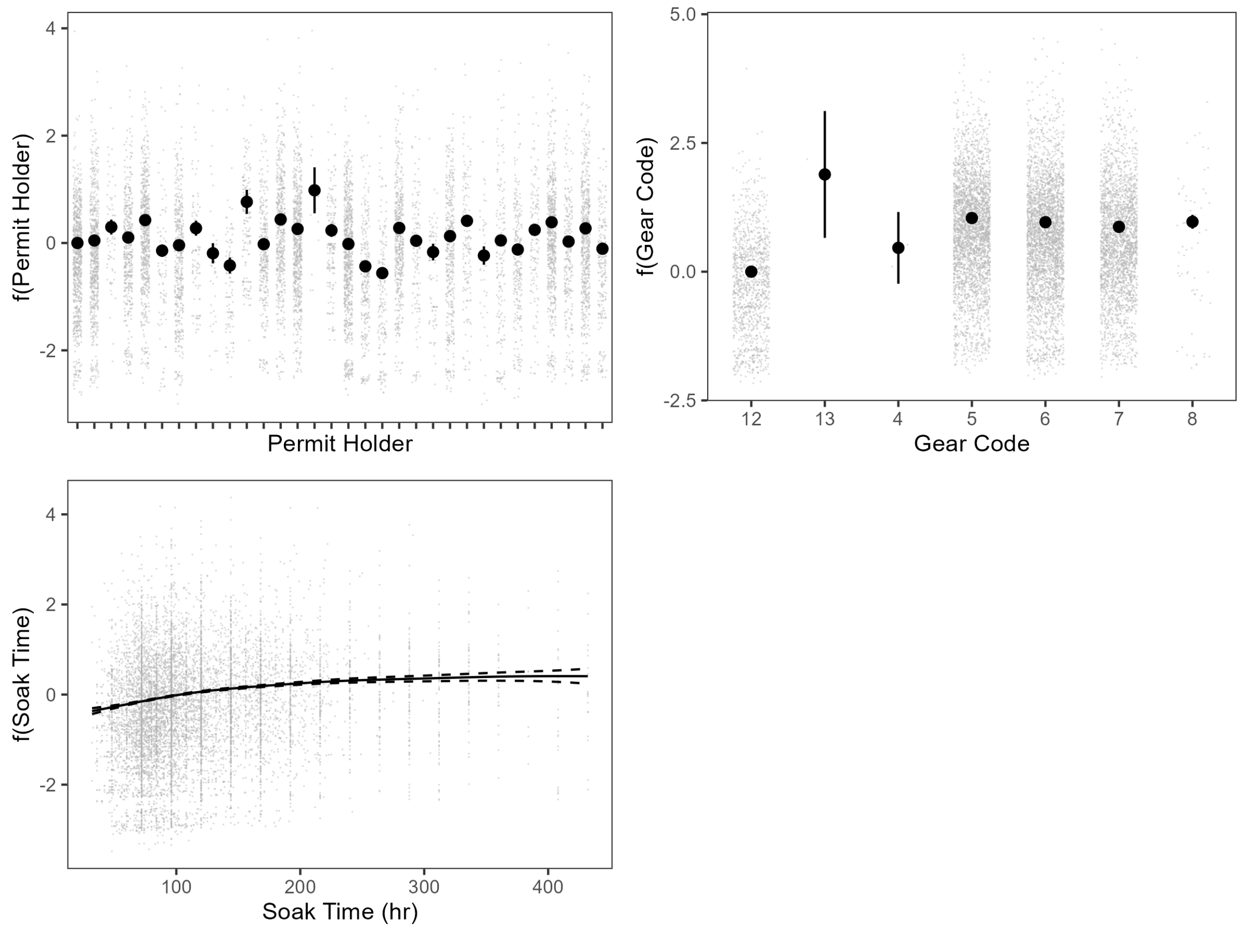

Figure 7: Marginal effects of permit holder, gear type, and soaktime with associated partial residuals for the model fit to legal CPUE including yr:block during pre-rationalized period in the EAG.

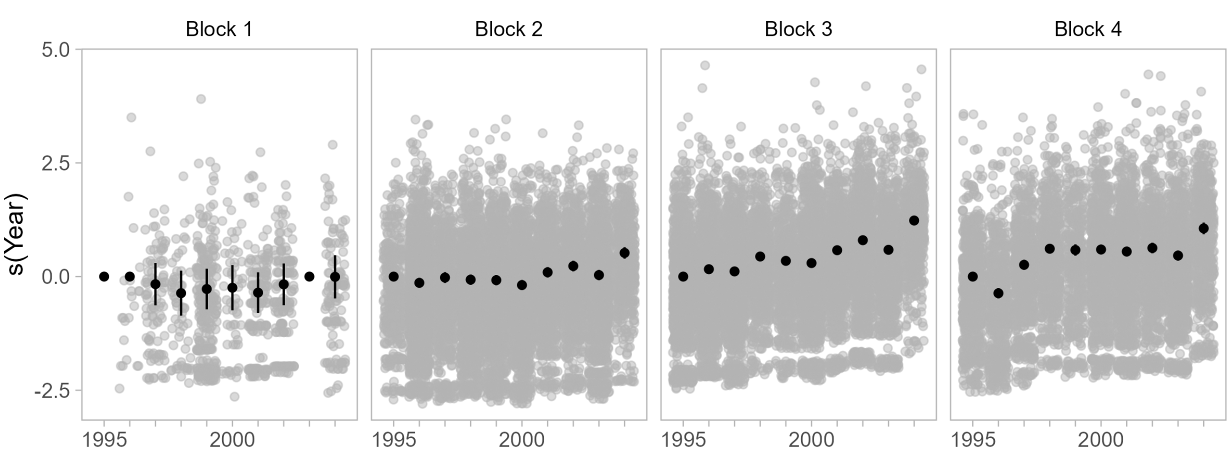

Figure 8: Marginal effect crab year by block with associated partial residuals for the model fit to legal CPUE during pre-rationalized period in the EAG.

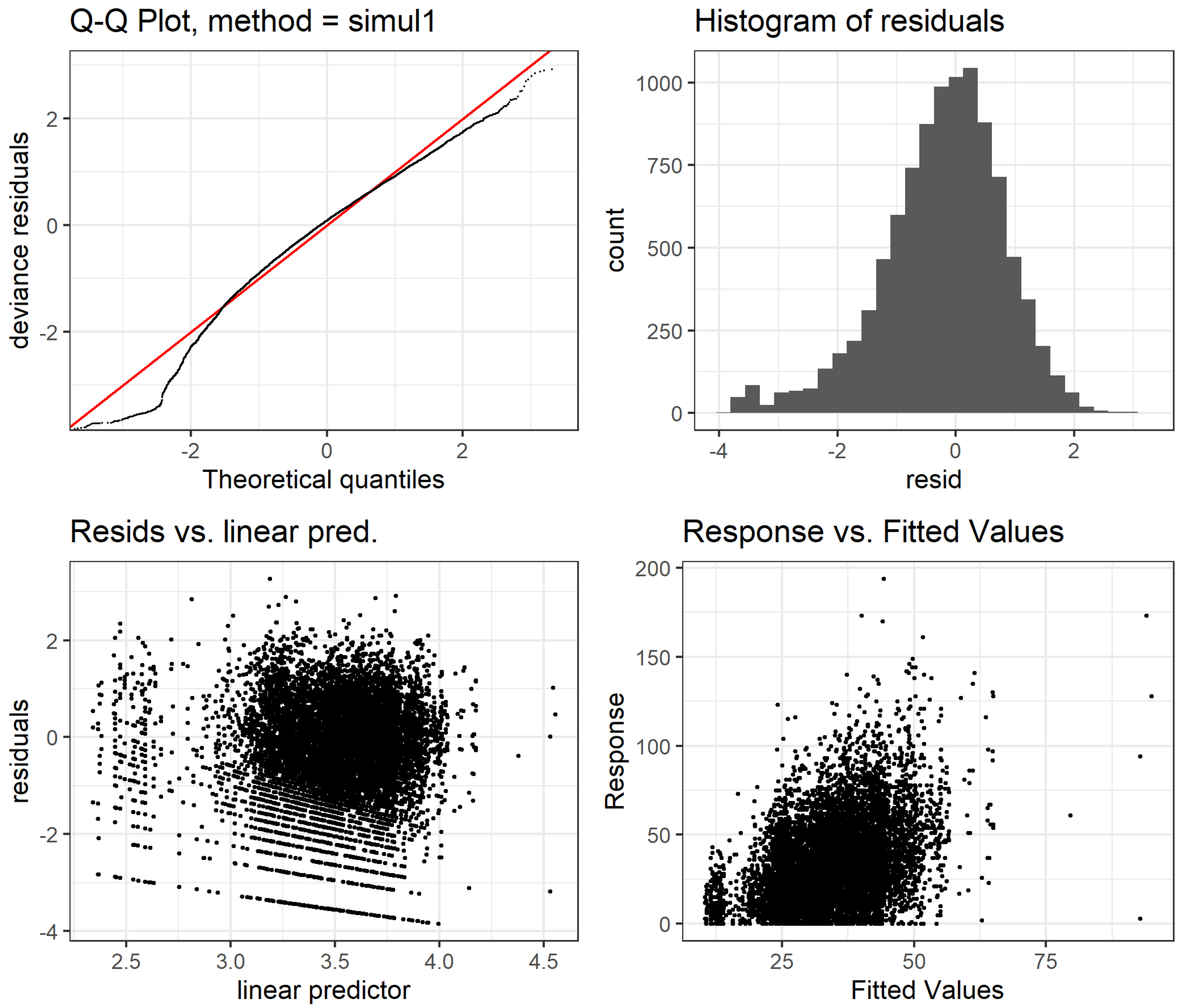

Figure 9: Diagnostic plots for the final GAM fit to legal CPUE during the post-rationalized period in the EAG.

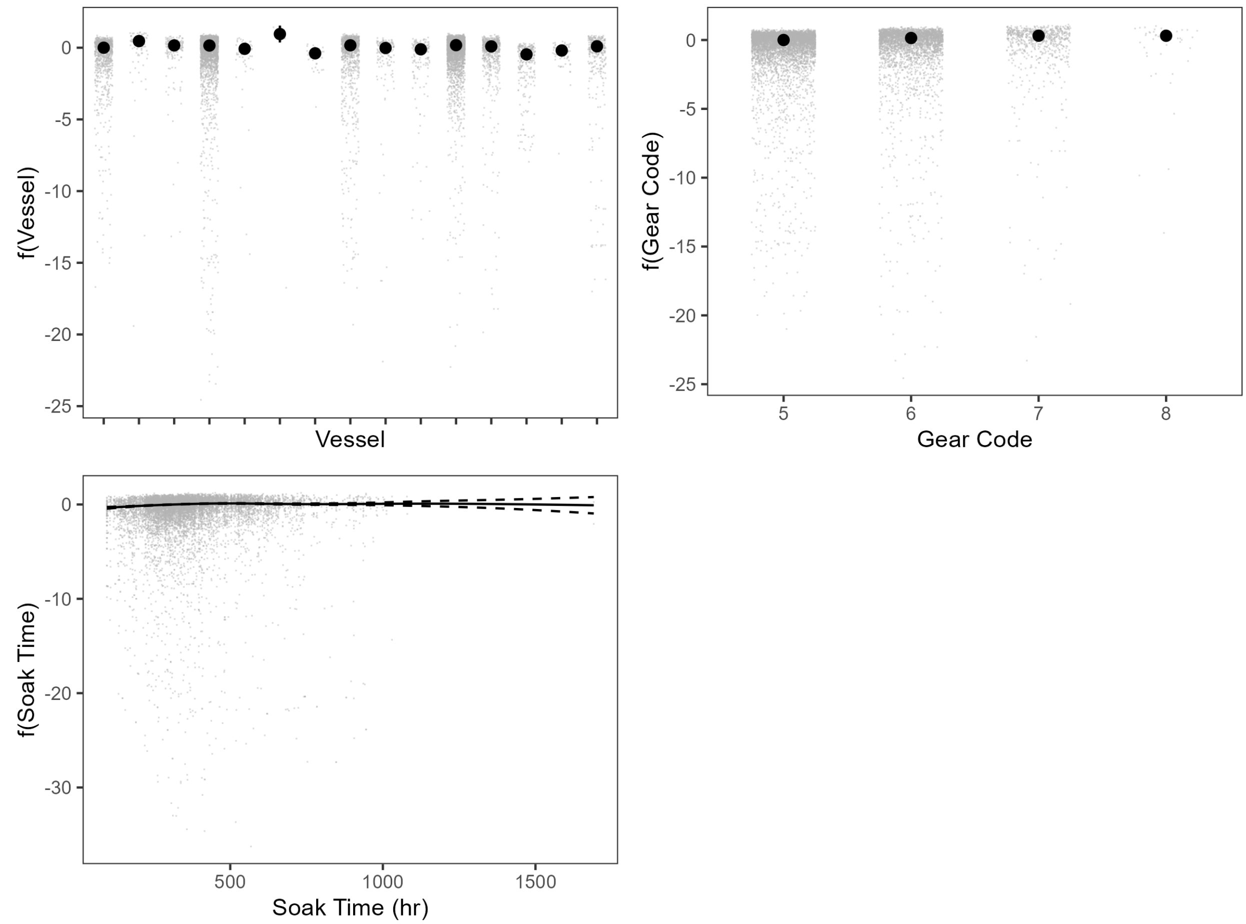

Figure 10: Marginal effects of permit holder, gear type, and soak time with associated partial residuals for the final model fit to legal CPUE during post-rationalized period in the EAG.

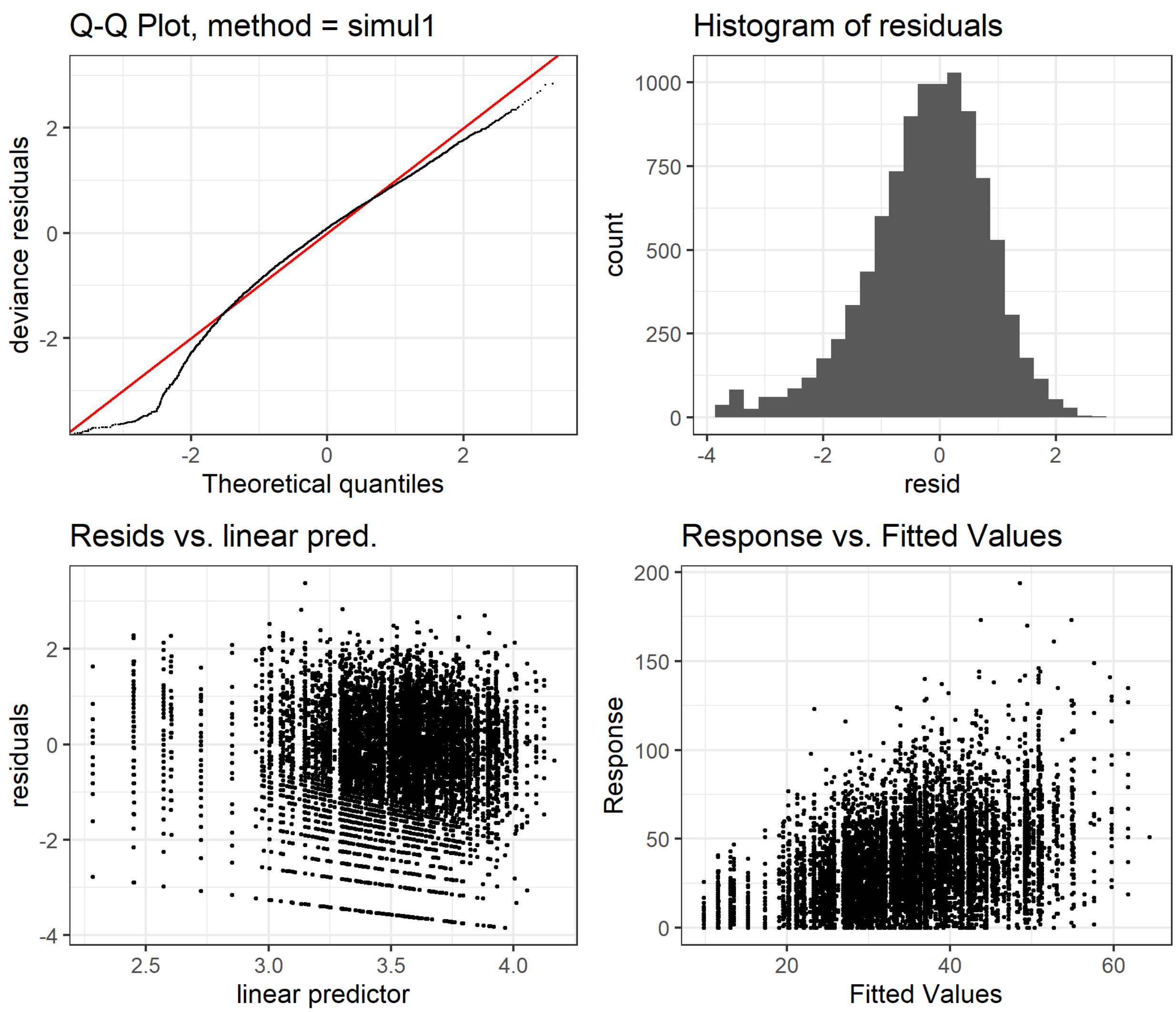

Figure 11: Diagnostic plots for the final GAM including year:block, fit to legal CPUE during the post-rationalized period in the EAG.

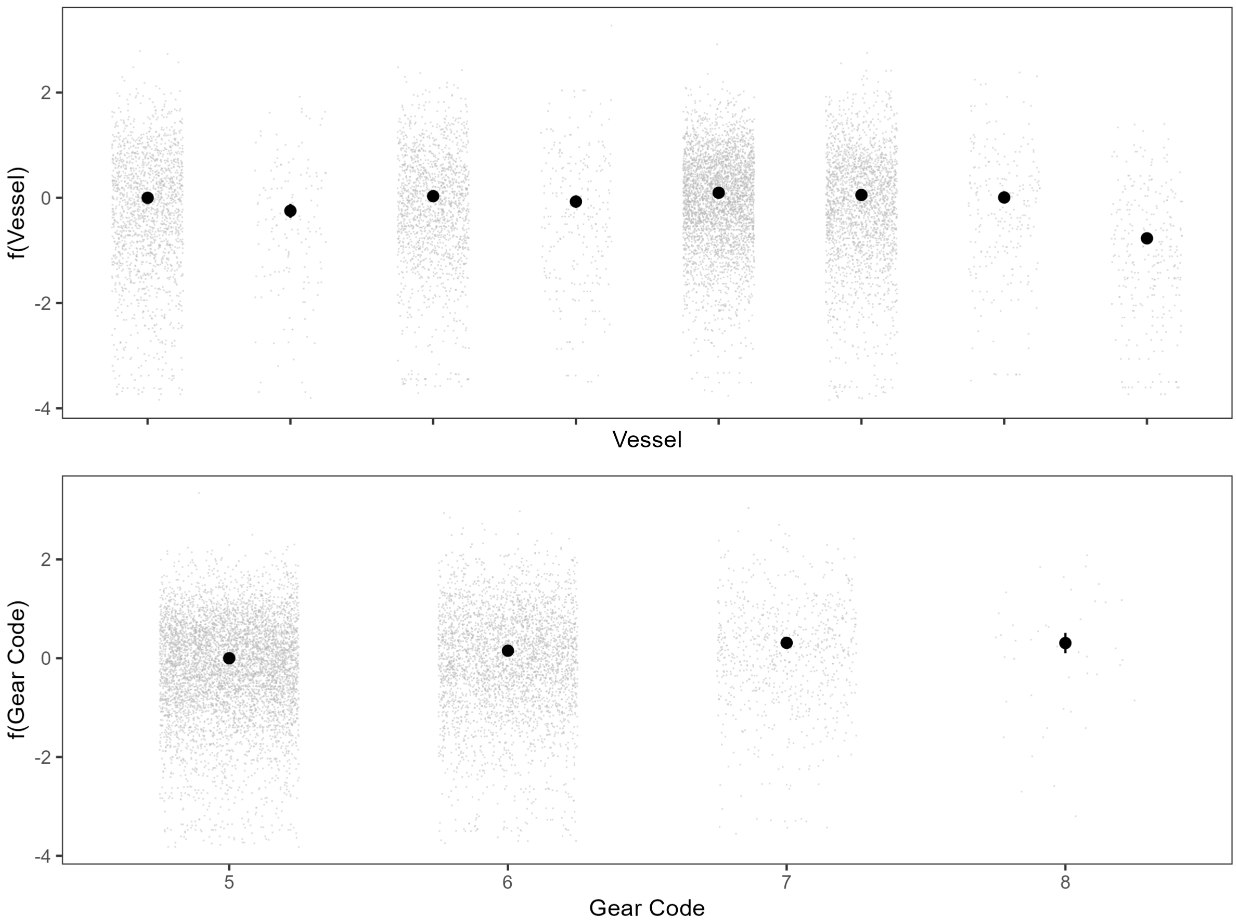

Figure 12: Marginal effects of permit holder, gear type, and soaktime with associated partial residuals for the model fit to legal CPUE including yr:block during post-rationalized period in the EAG.

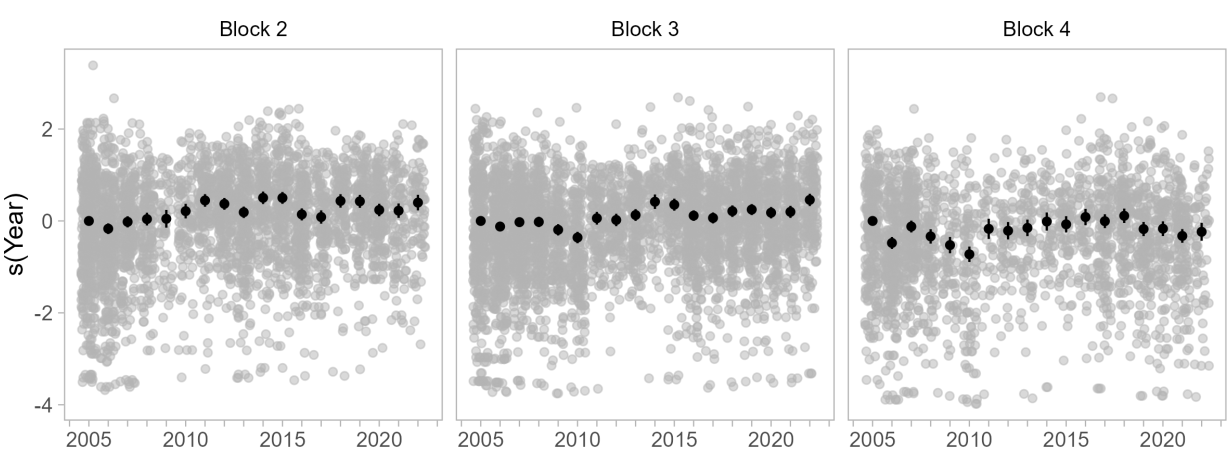

Figure 13: Marginal effect crab year by block with associated partial residuals for the model fit to legal CPUE during post-rationalized period in the EAG.

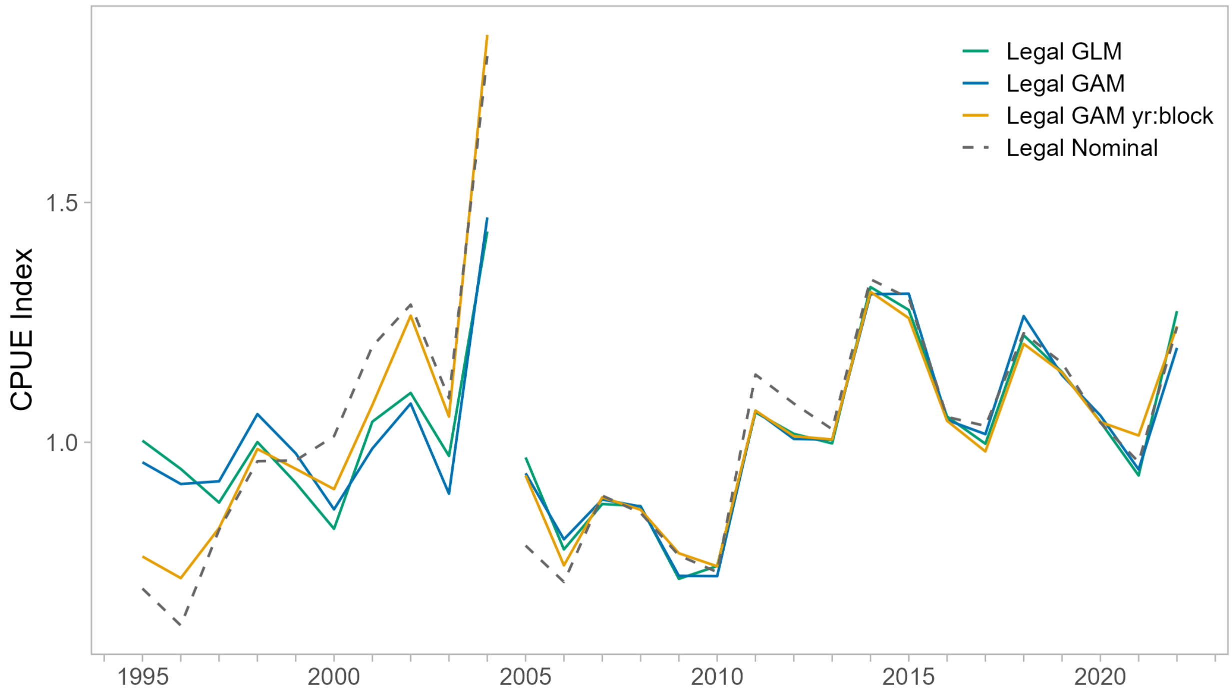

Figure 14: Time series of standardized legal CPUE indices estimated for the EAG.

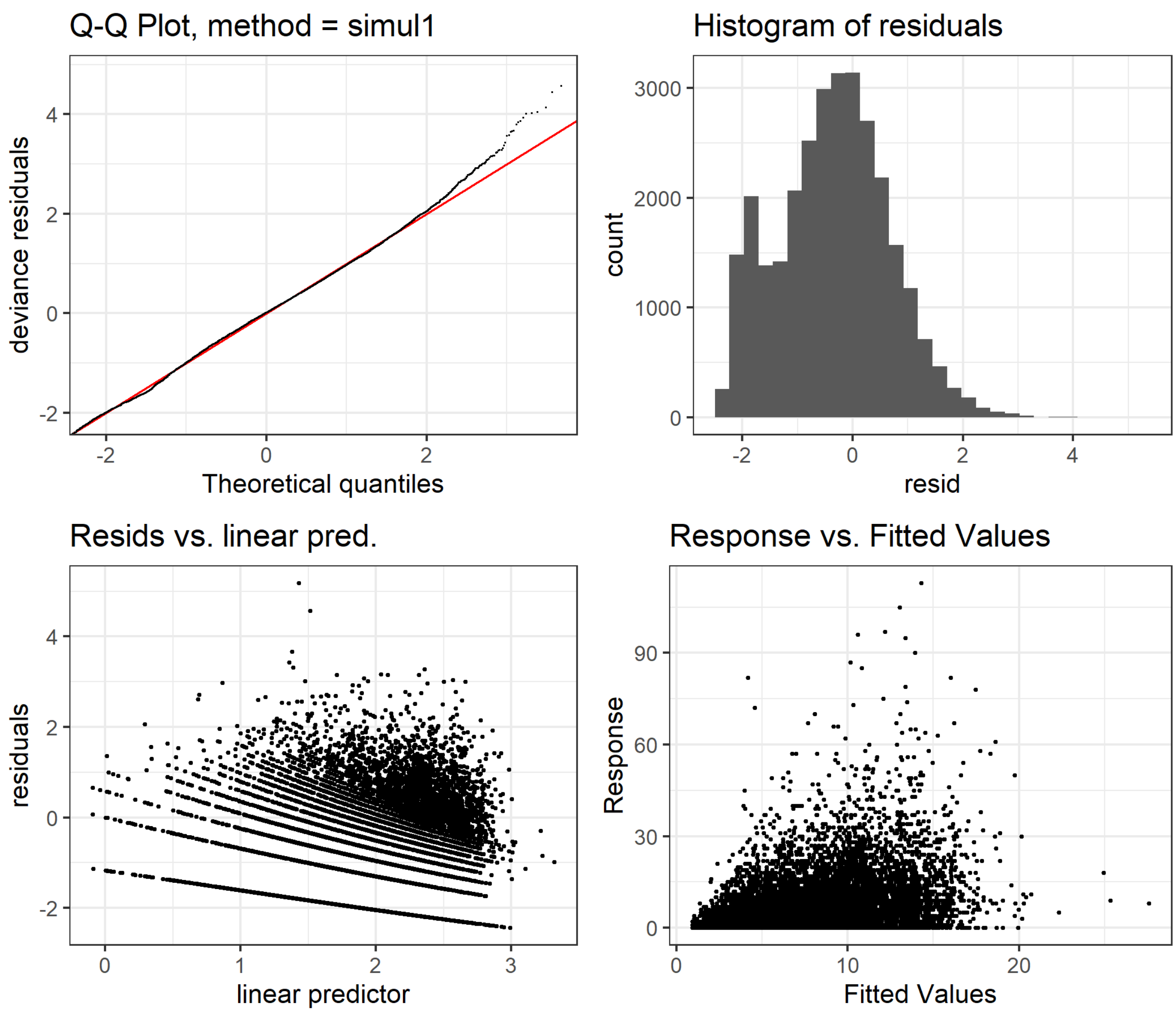

Figure 15: Diagnostic plots for the final GAM fit to legal CPUE during the pre-rationalized period in the WAG.

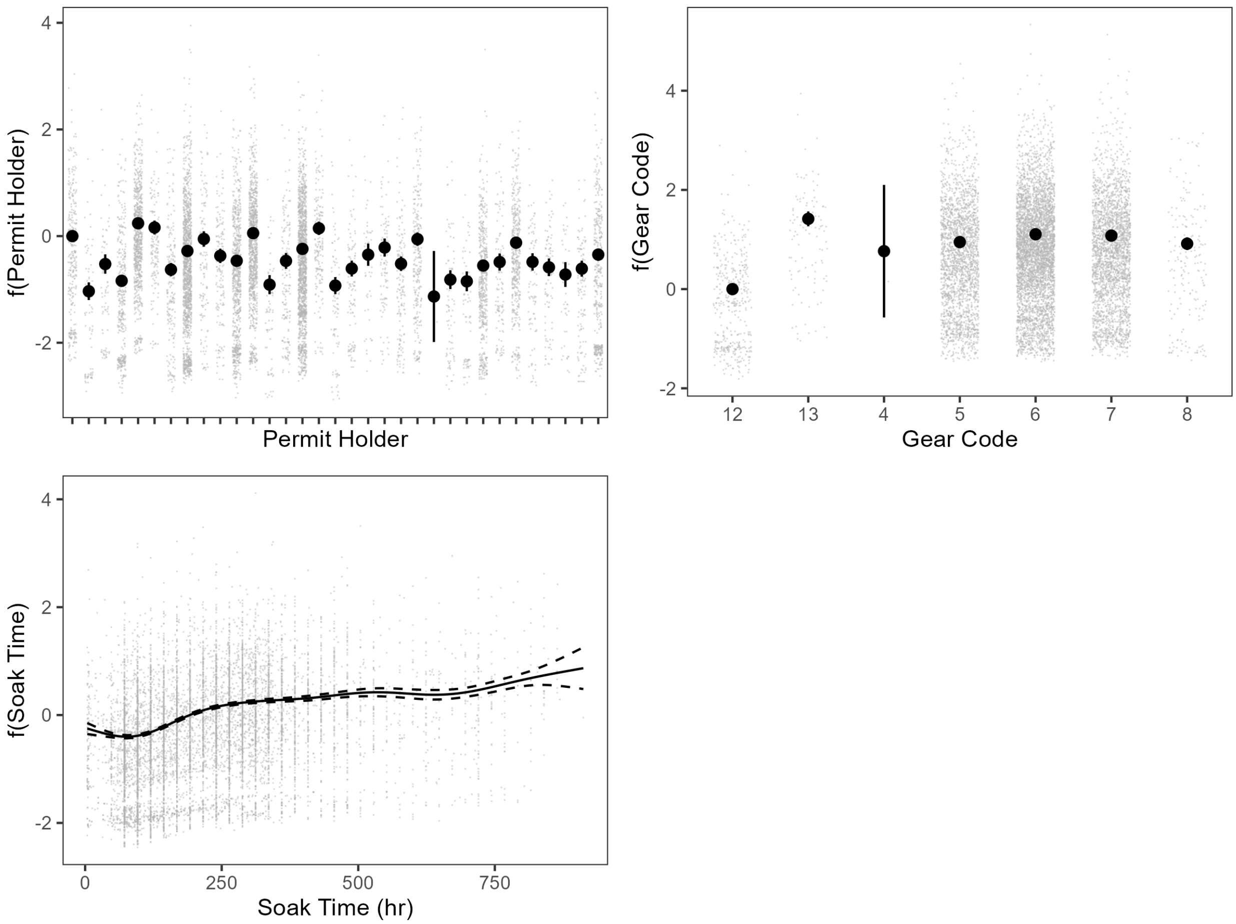

Figure 16: Marginal effects of permit holder, gear type, and soaktime with associated partial residuals for the final model fit to legal CPUE during pre-rationalized period in the WAG.

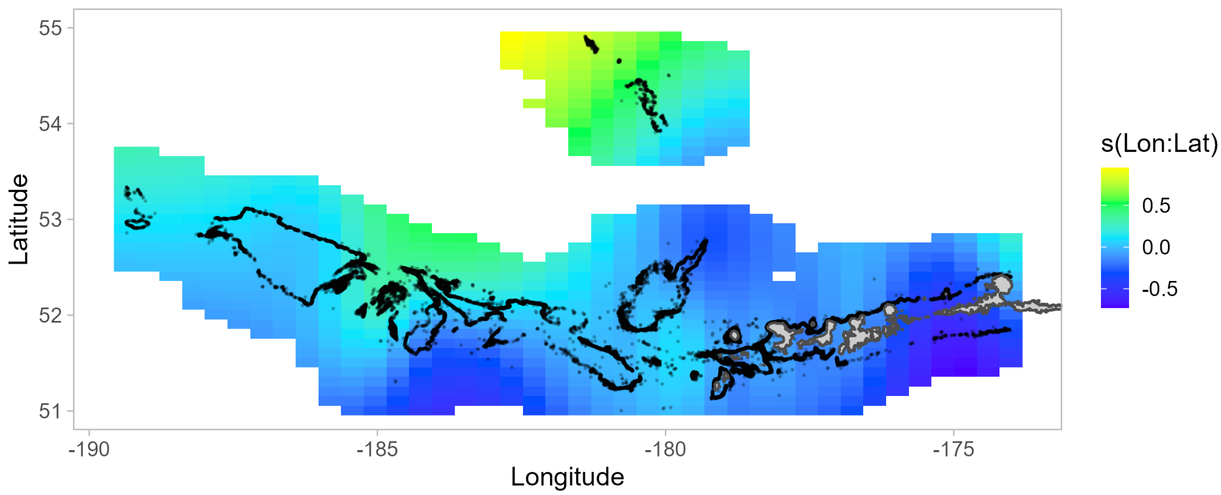

Figure 17: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to legal CPUE during pre-rationalized period in the WAG.

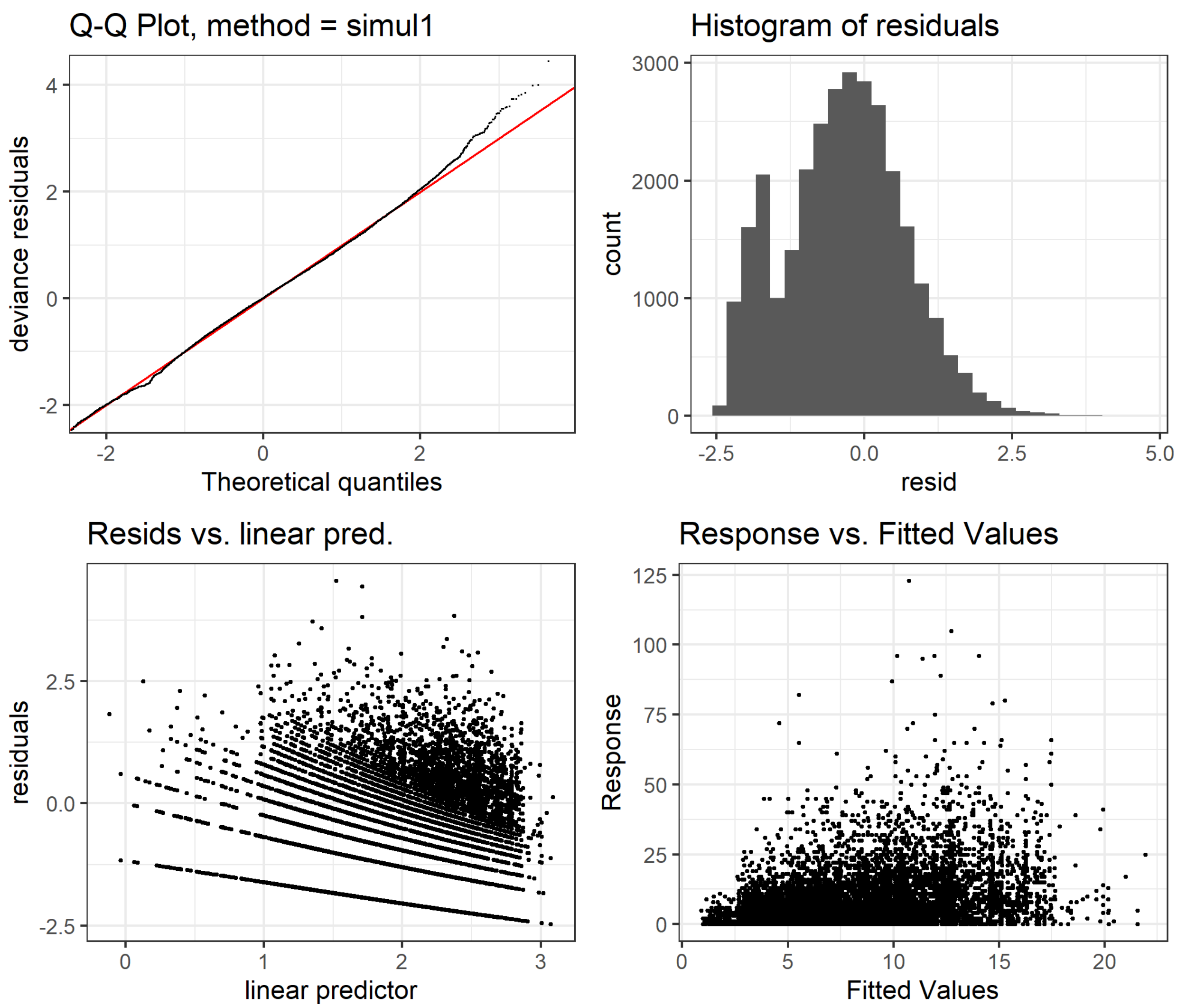

Figure 18: Diagnostic plots for the final GAM including year:block, fit to legal CPUE during the pre-rationalized period in the WAG.

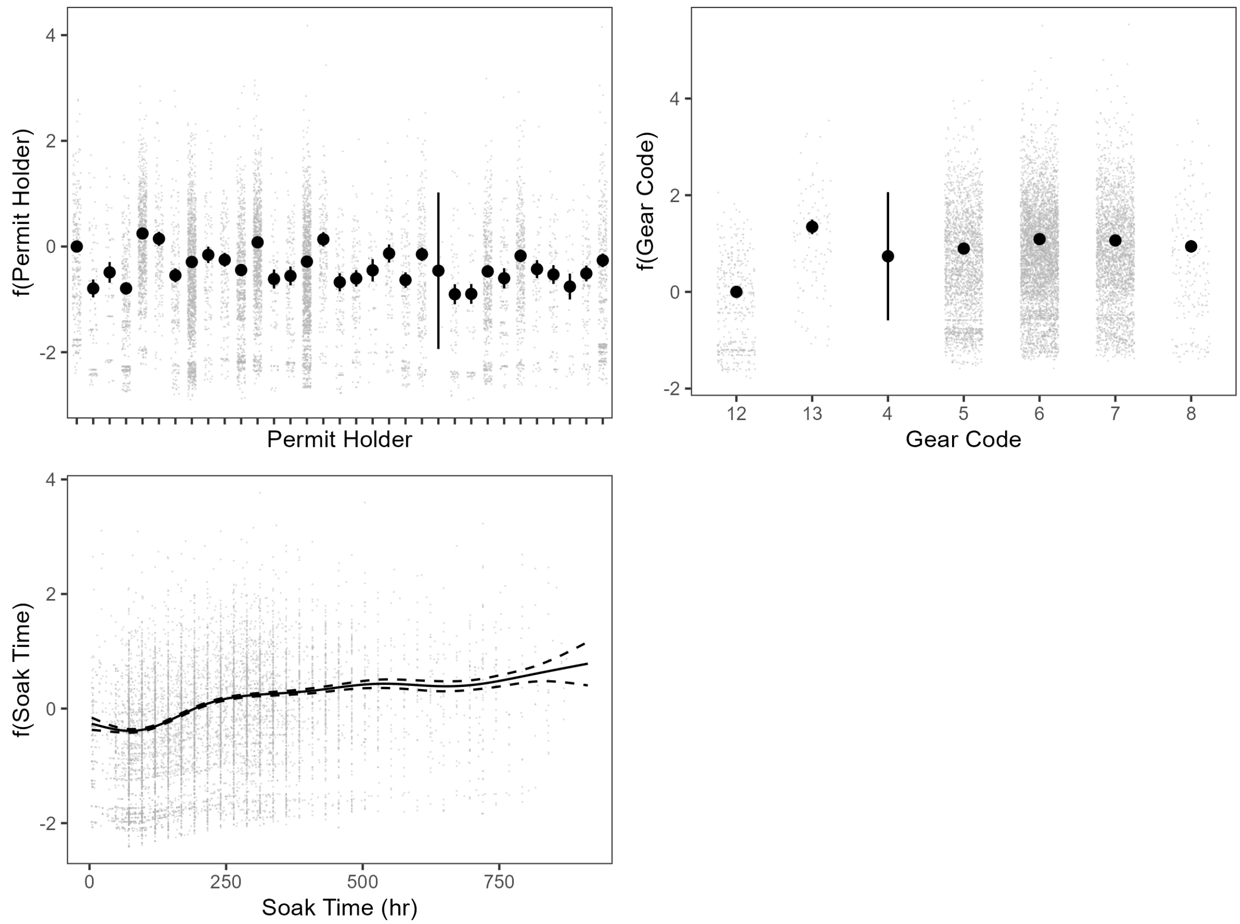

Figure 19: Marginal effects of permit holder, gear type, and soaktime with associated partial residuals for the model fit to legal CPUE including yr:block during pre-rationalized period in the WAG.

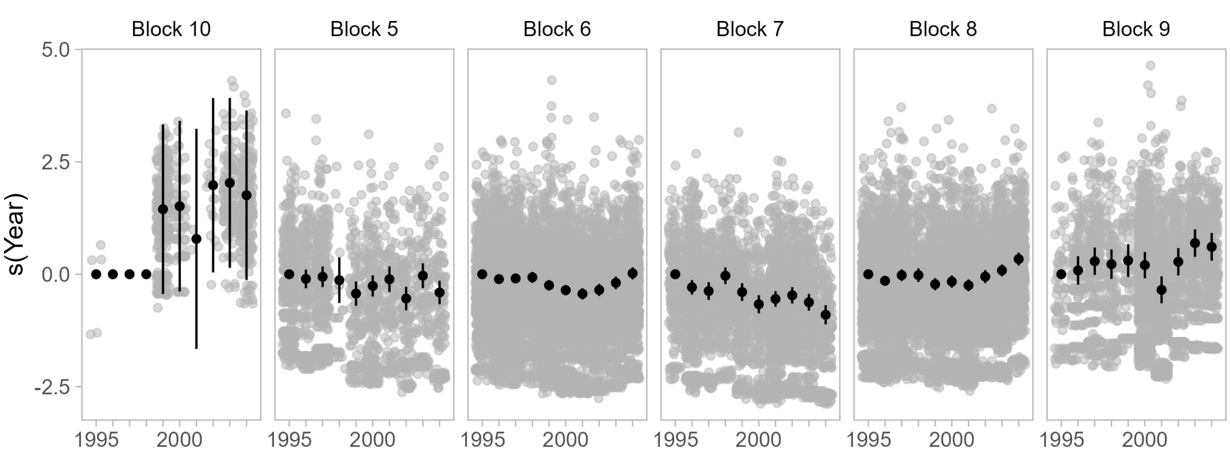

Figure 20: Marginal effect crab year by block with associated partial residuals for the model fit to legal CPUE during pre-rationalized period in the WAG.

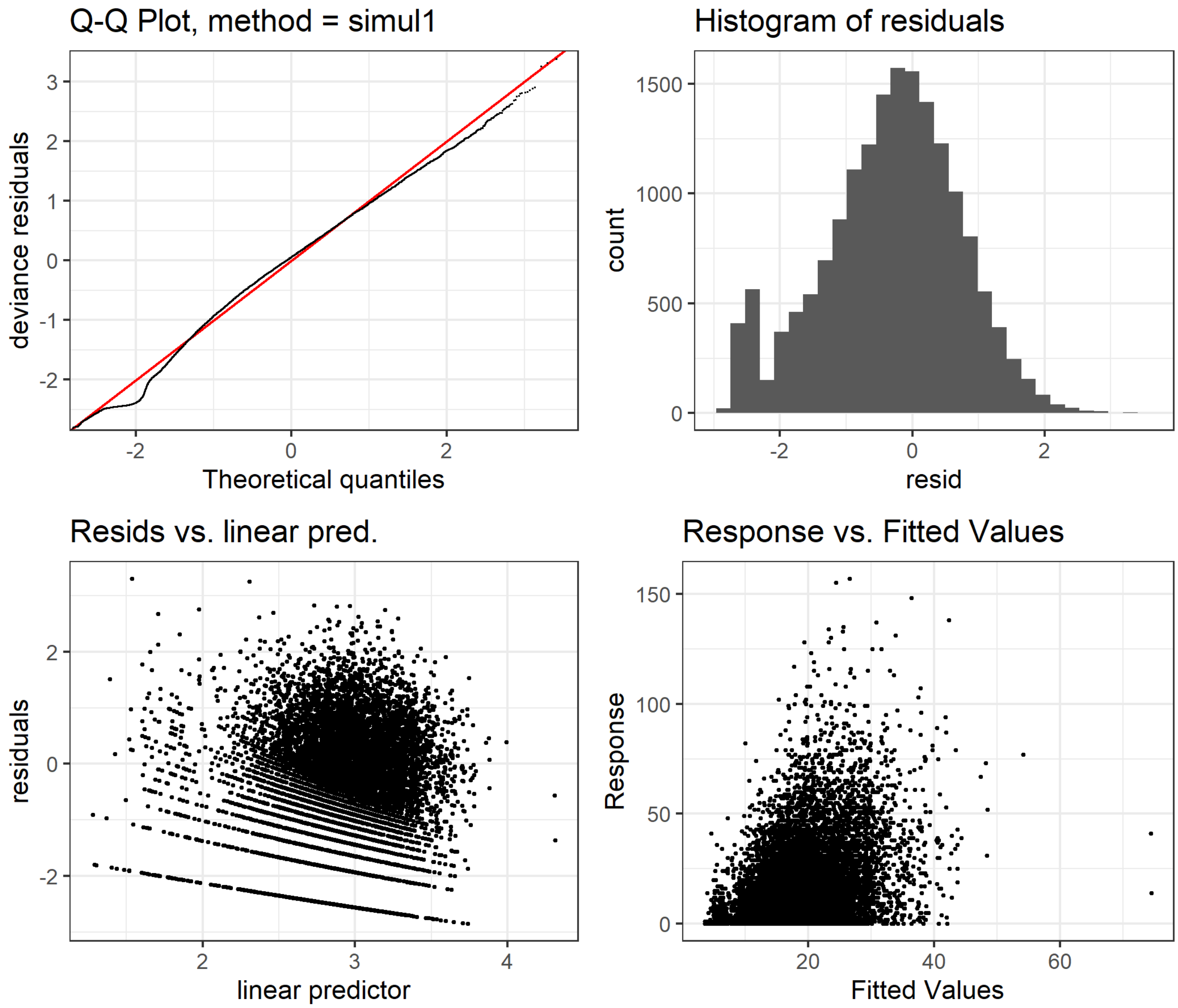

Figure 21: Diagnostic plots for the final GAM fit to legal CPUE during the post-rationalized period in the WAG.

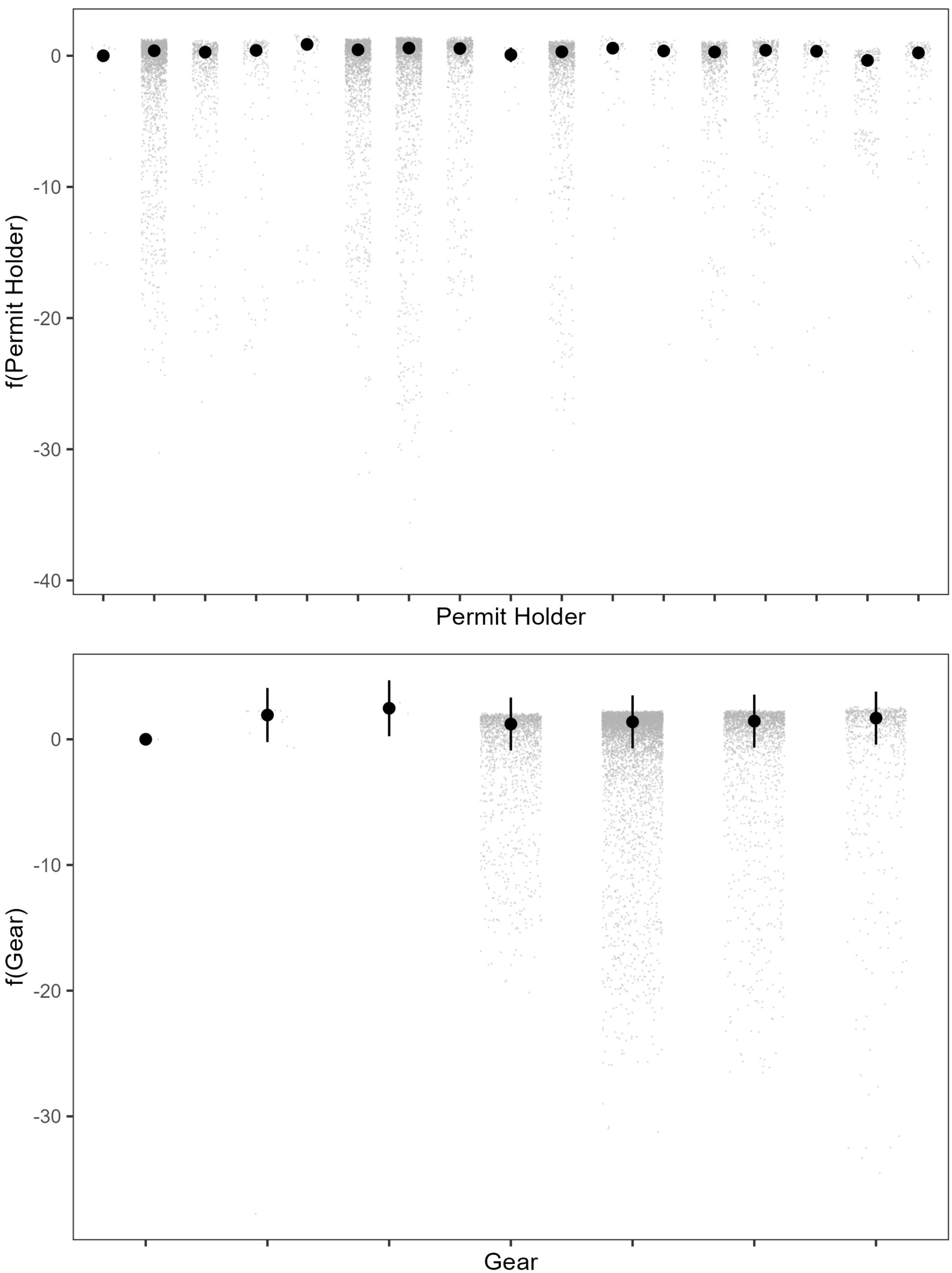

Figure 22: Marginal effects of permit holder, gear type, and soak time with associated partial residuals for the final model fit to legal CPUE during post-rationalized period in the WAG.

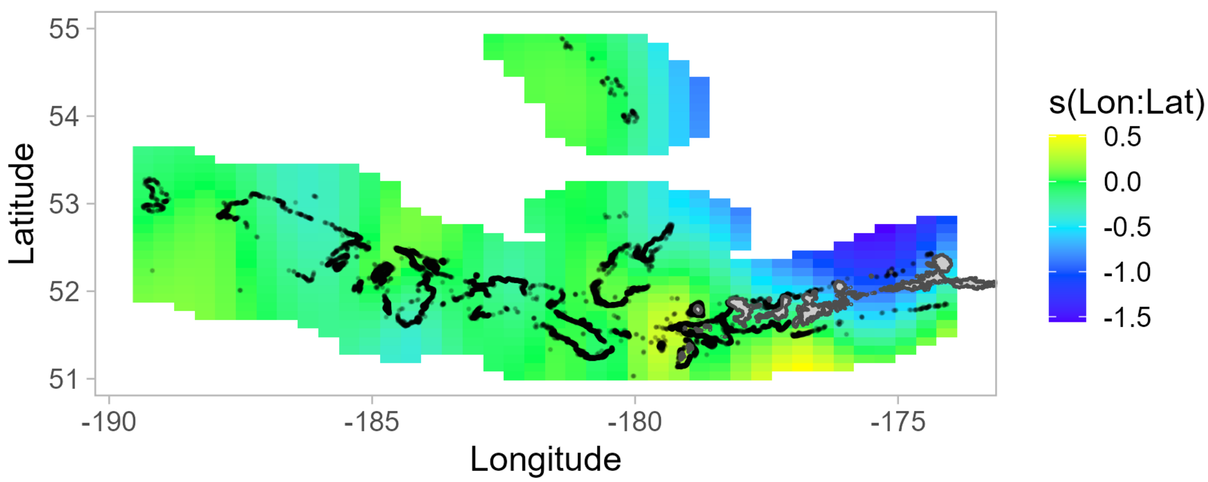

Figure 23: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to legal CPUE during post-rationalized period in the WAG.

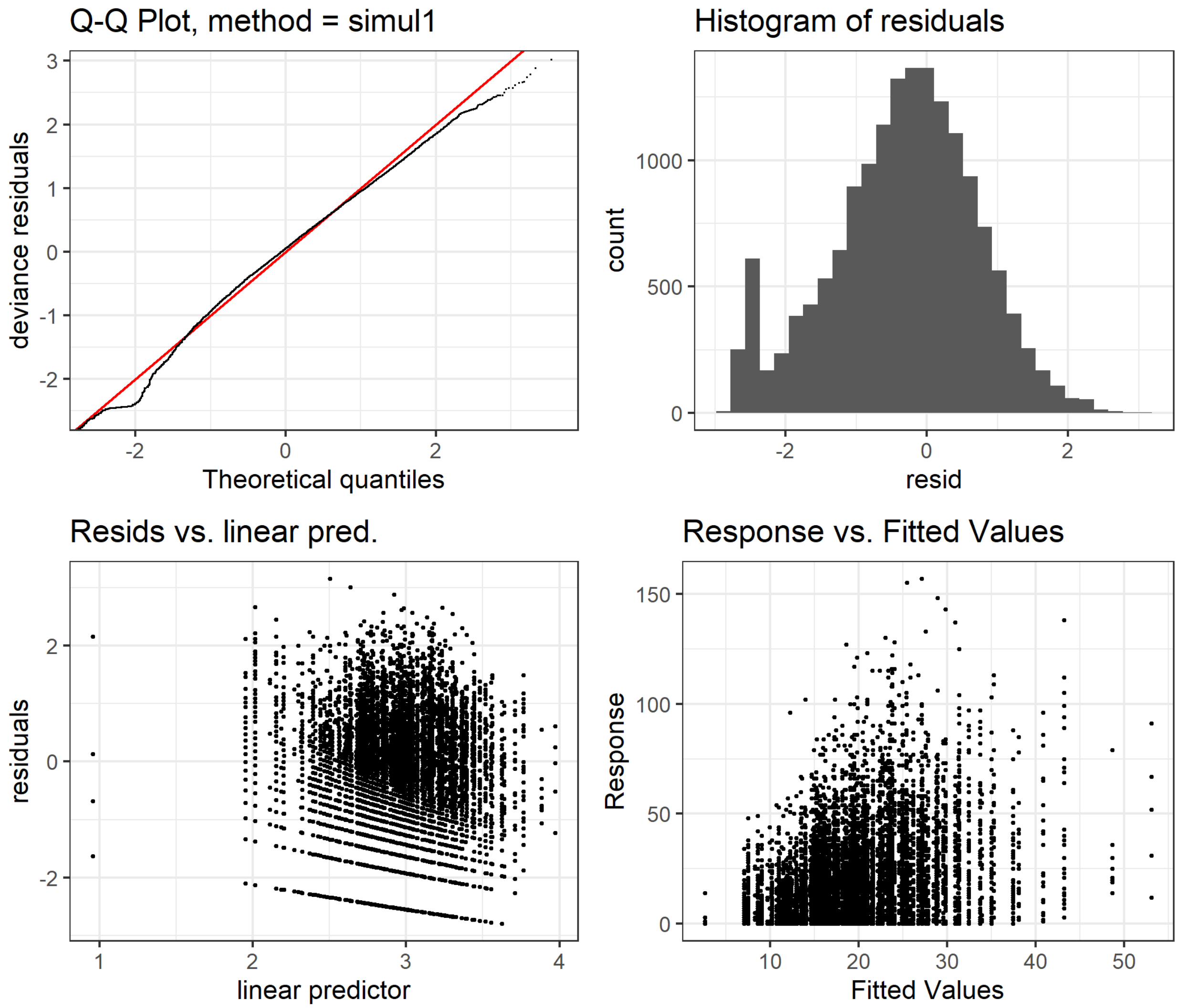

Figure 24: Diagnostic plots for the final GAM including year:block, fit to legal CPUE during the post-rationalized period in the WAG.

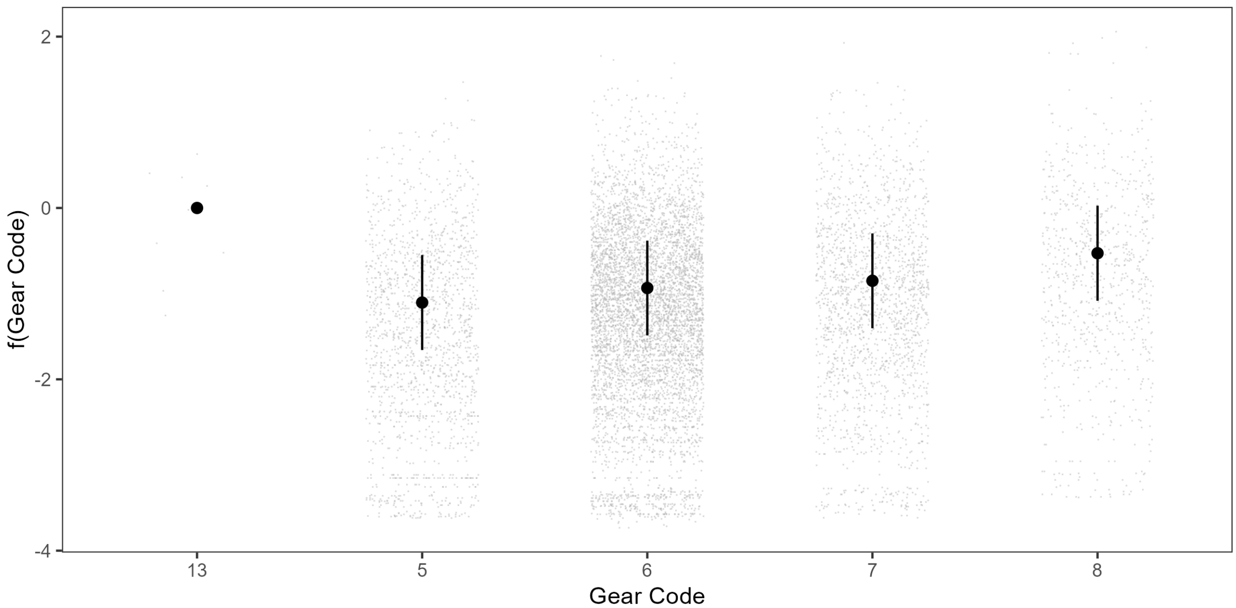

Figure 25: Marginal effect of gear type with associated partial residuals for the model fit to legal CPUE including yr:block during post-rationalized period in the EAG.

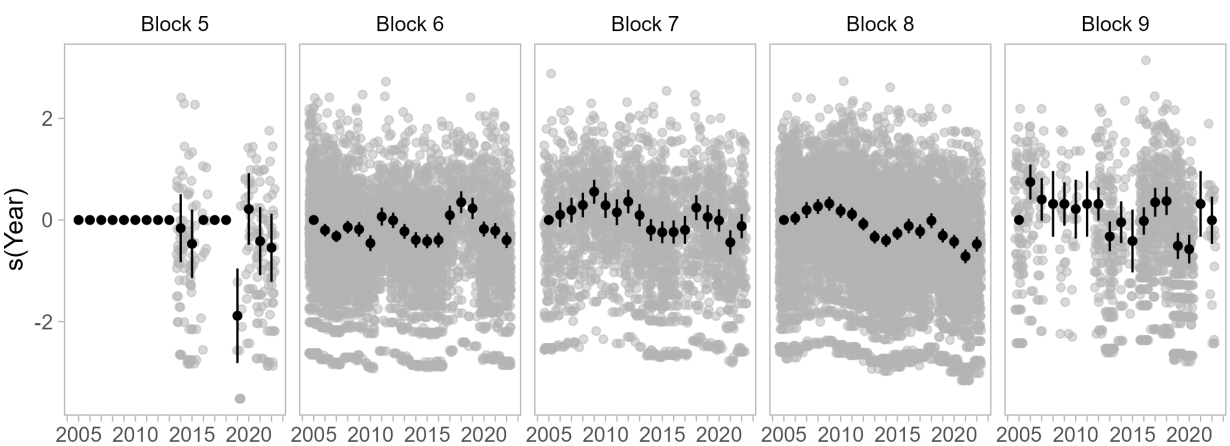

Figure 26: Marginal effect crab year by block with associated partial residuals for the model fit to legal CPUE during post-rationalized period in the WAG.

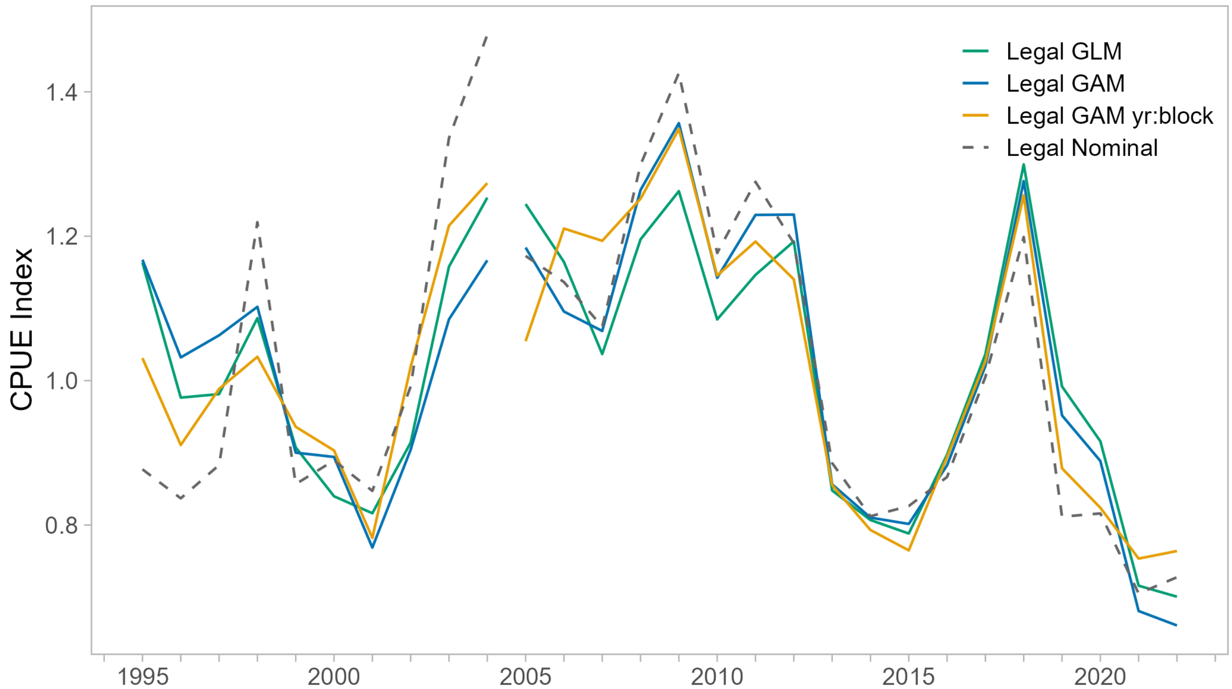

Figure 27: Time series of standardized legal CPUE indices estimated for the WAG.

Figure 28: Diagnostic plots for the final GAM fit to total CPUE during the pre-rationalized period in the EAG.

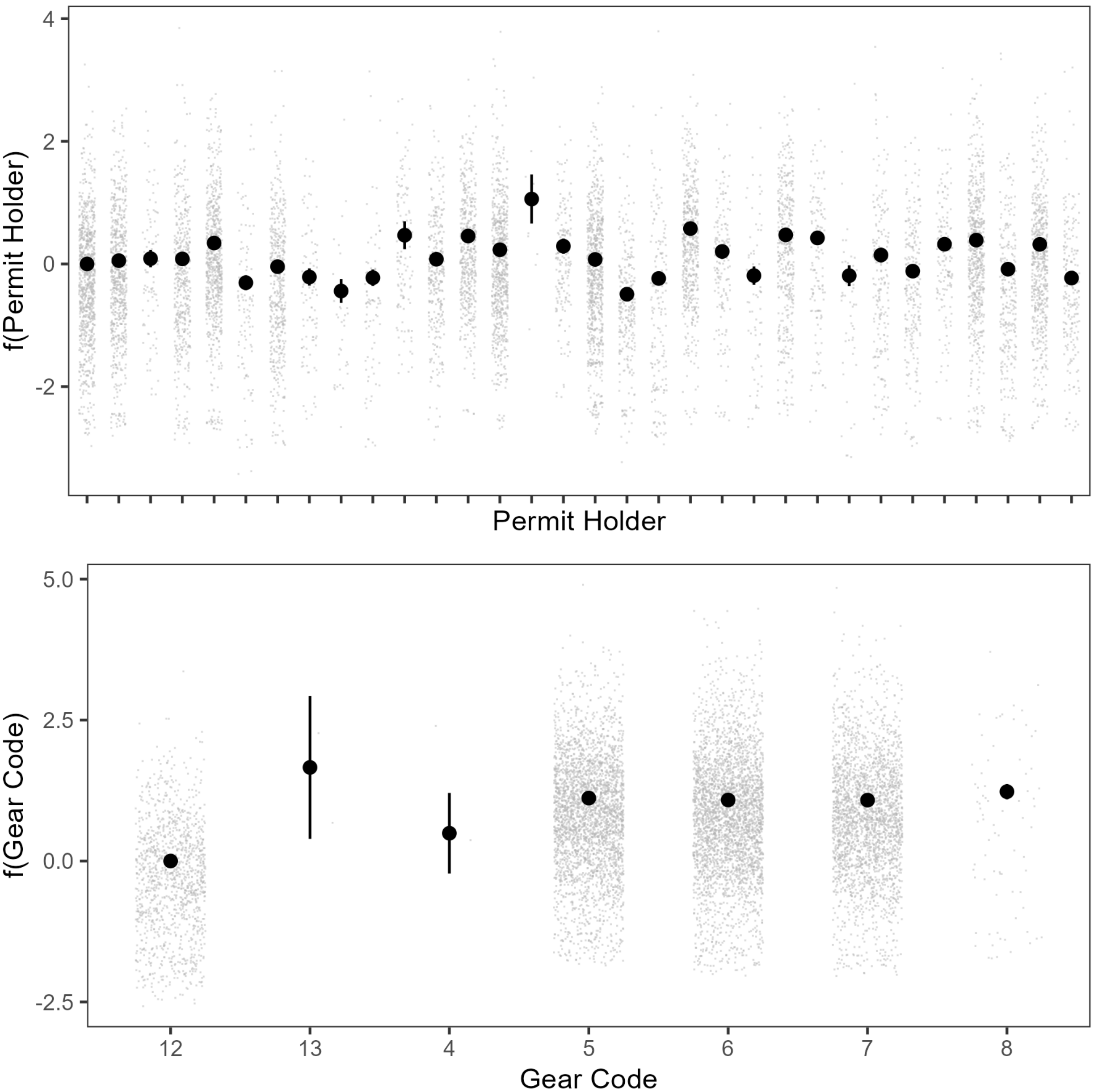

Figure 29: Marginal effects of permit holder and gear type with associated partial residuals for the final model fit to total CPUE during pre-rationalized period in the EAG.

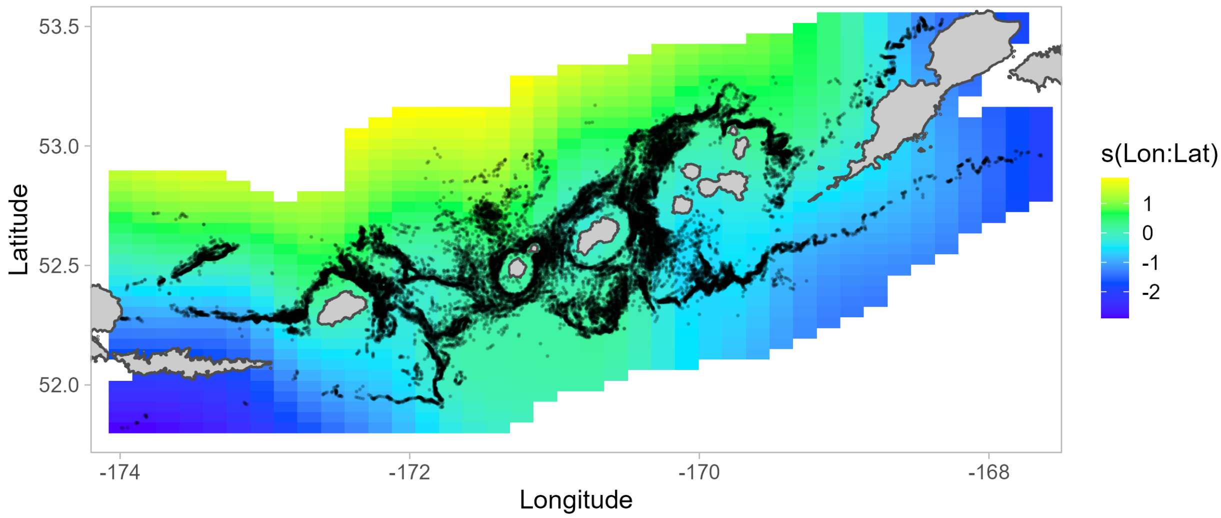

Figure 30: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to total CPUE during pre-rationalized period in the EAG.

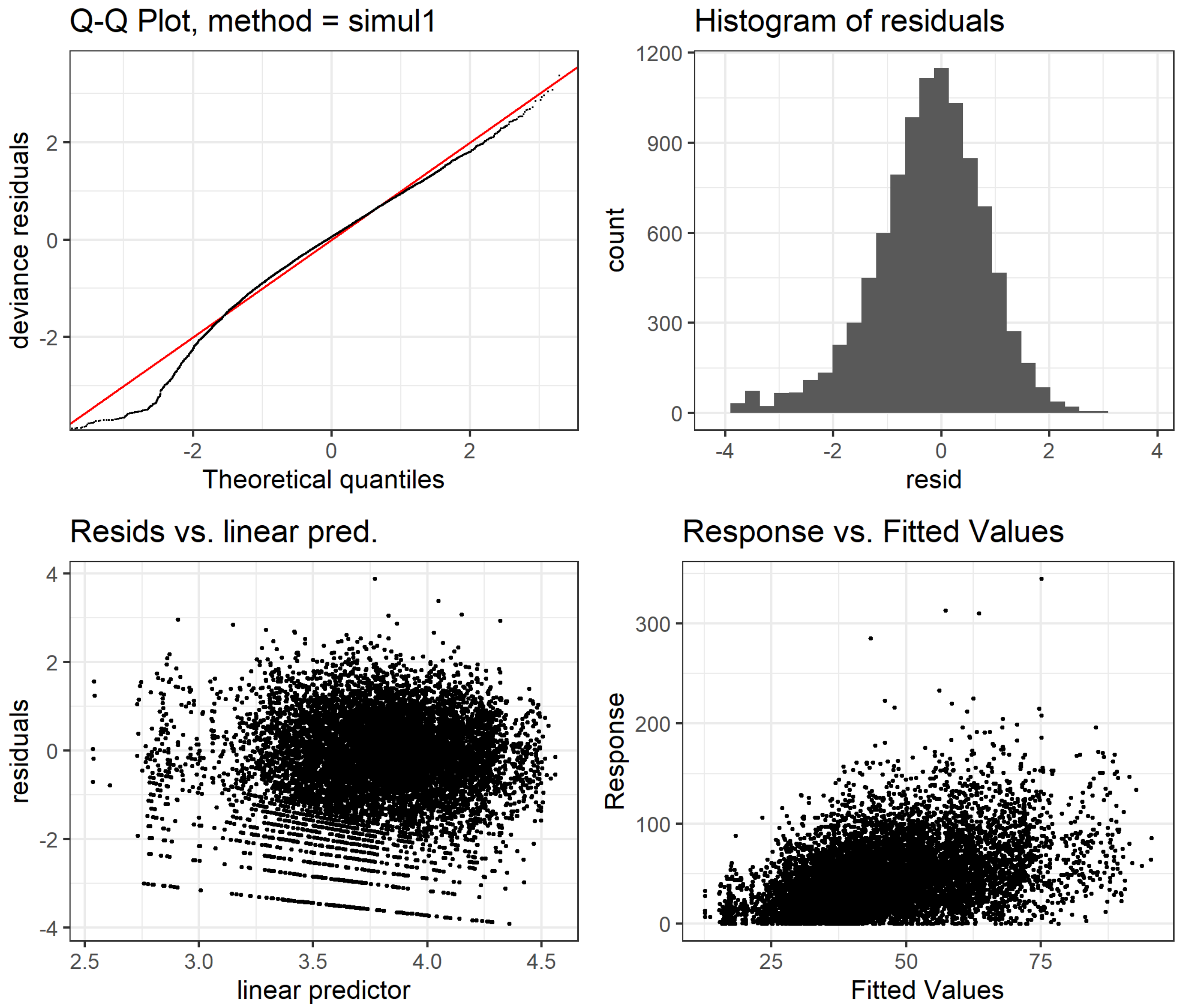

Figure 31: Diagnostic plots for the final GAM fit to total CPUE during the post-rationalized period in the EAG.

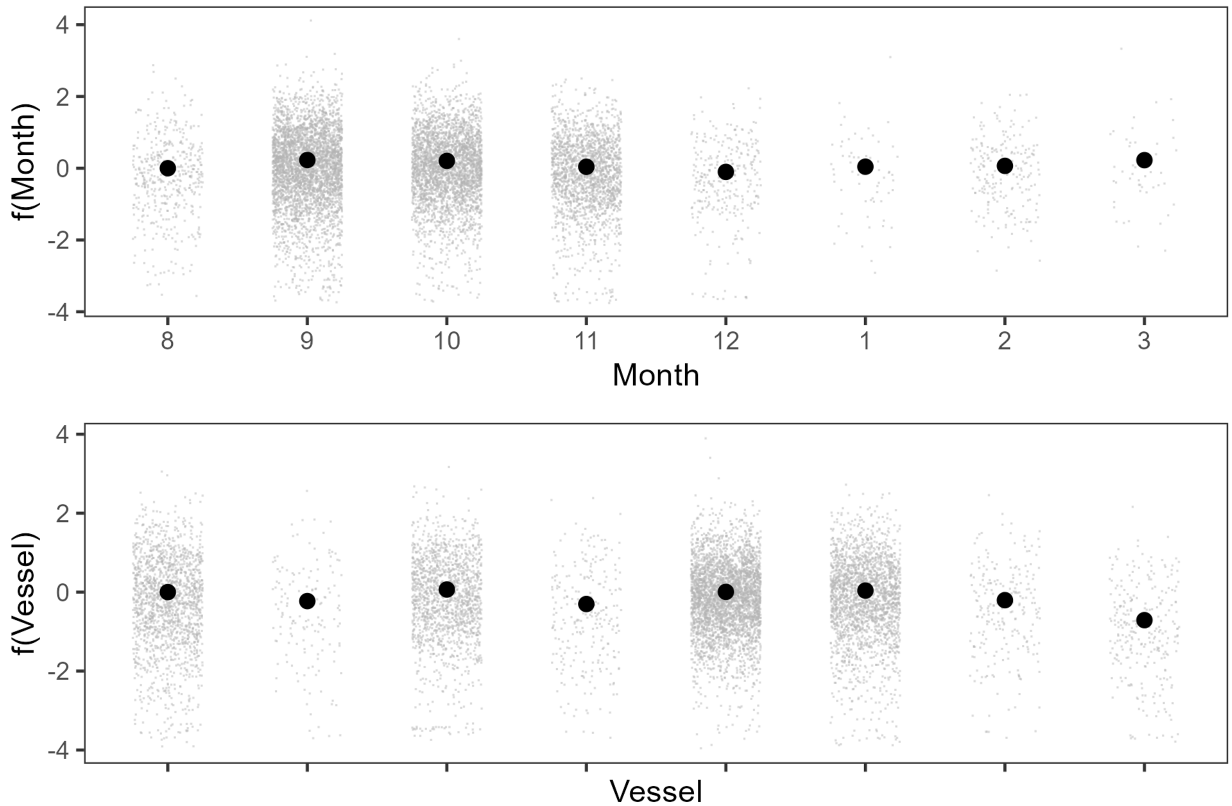

Figure 32: Marginal effects of permit holder with associated partial residuals for the final model fit to total CPUE during post-rationalized period in the EAG.

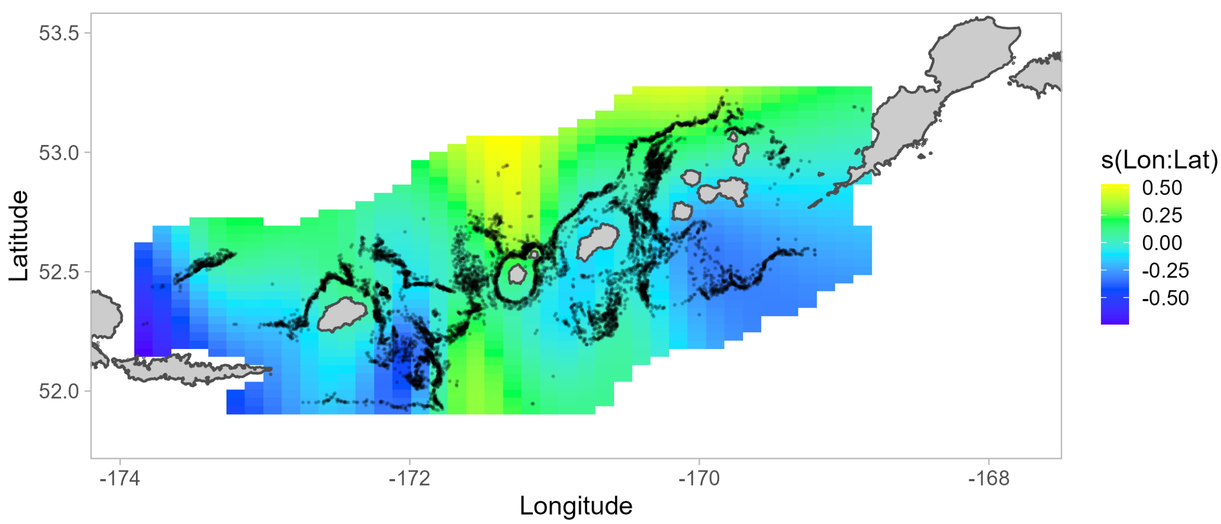

Figure 33: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to total CPUE during post-rationalized period in the EAG.

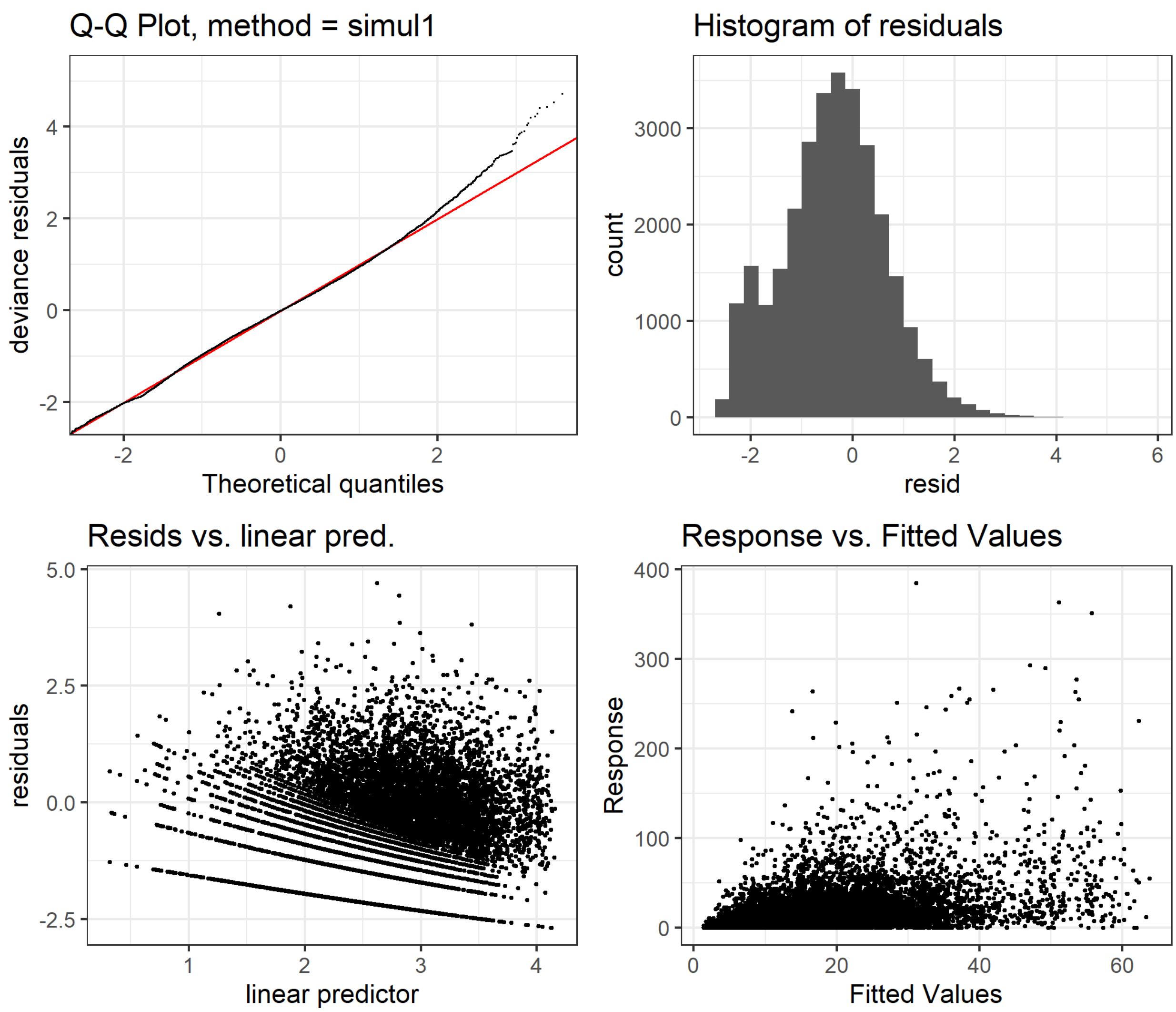

Figure 34: Diagnostic plots for the final GAM fit to total CPUE during the pre-rationalized period in the WAG.

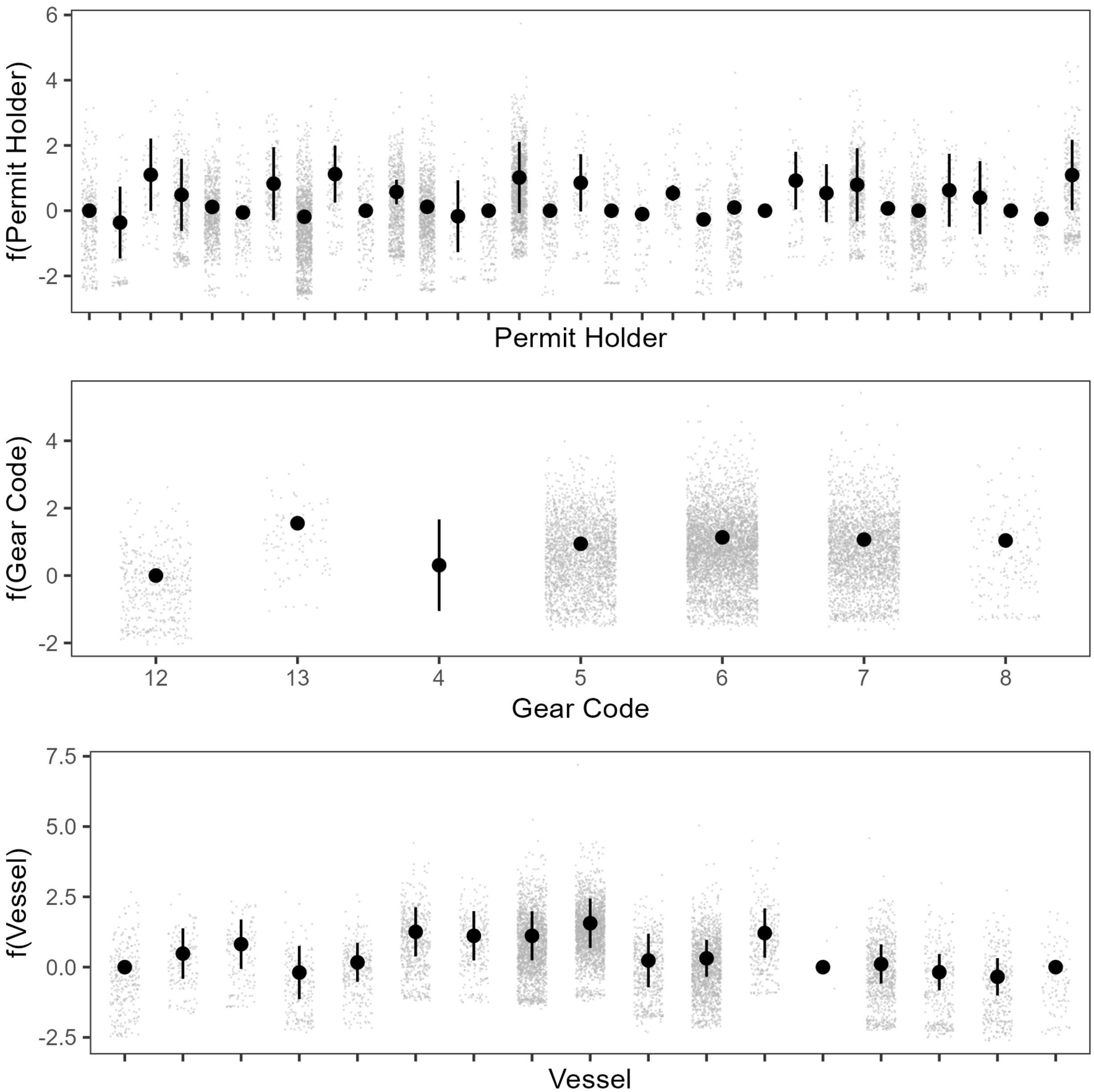

Figure 35: Marginal effects of permit holder and gear type with associated partial residuals for the final model fit to total CPUE during pre-rationalized period in the WAG.

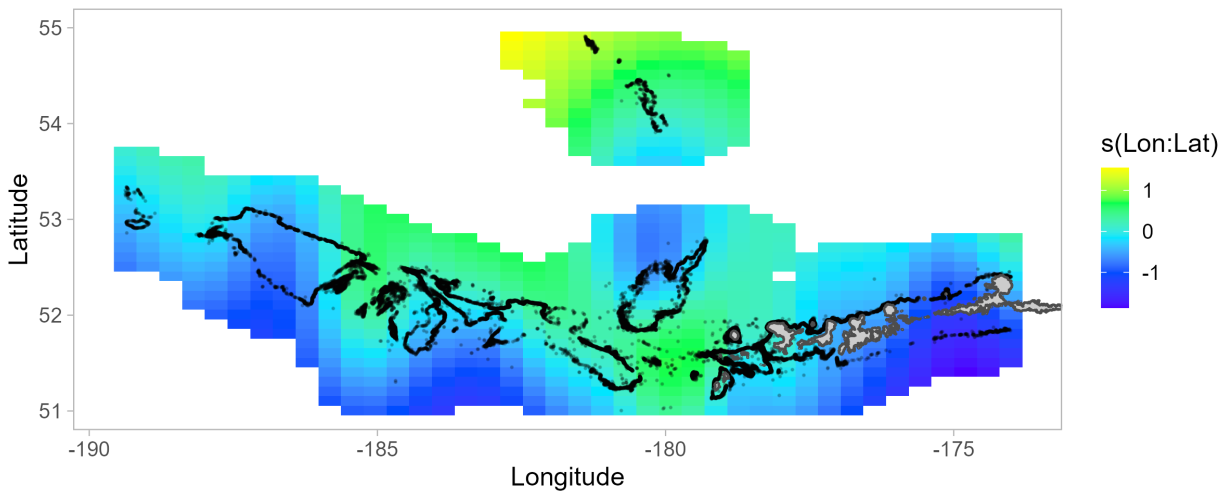

Figure 36: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to total CPUE during pre-rationalized period in the WAG.

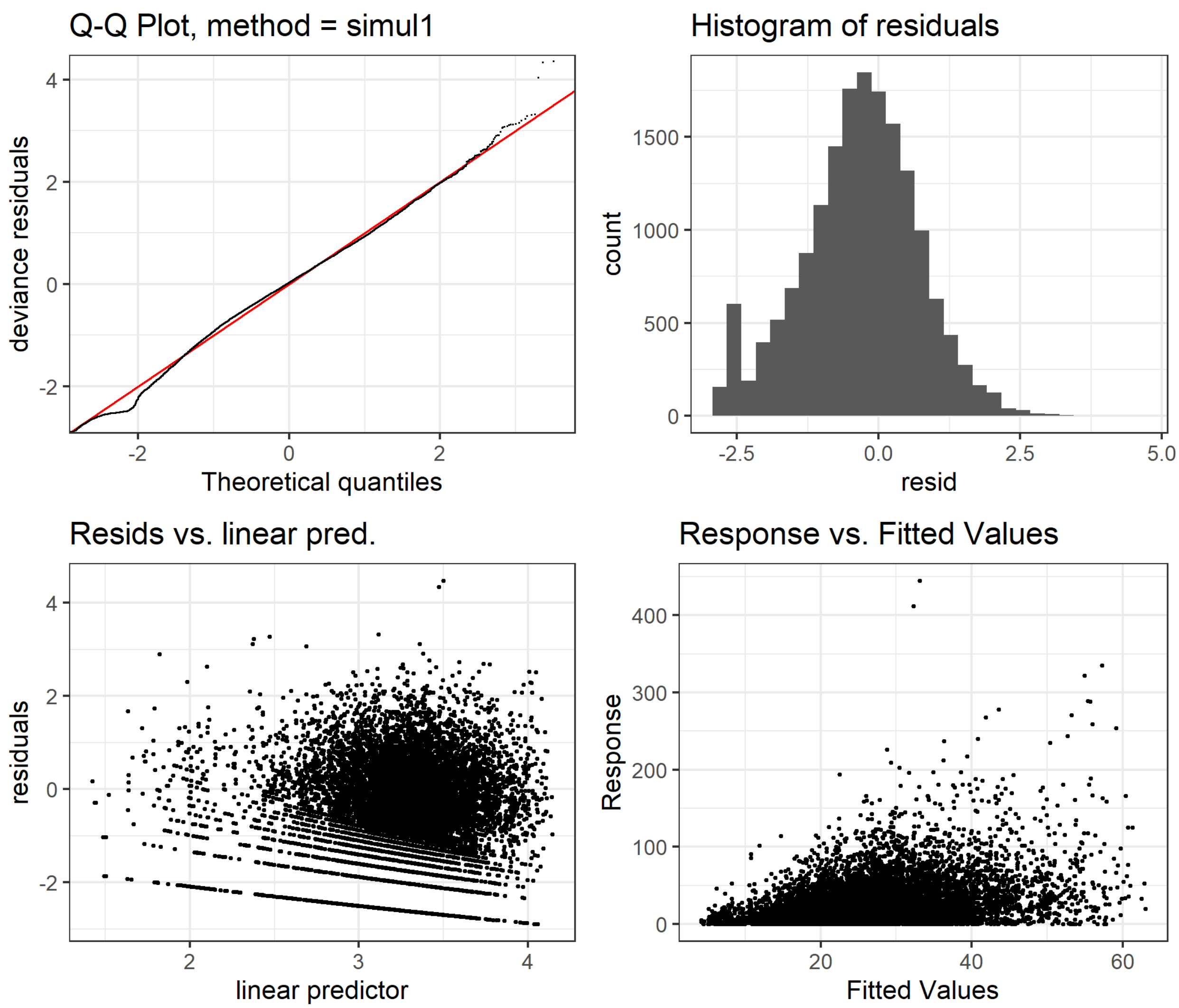

Figure 37: Diagnostic plots for the final GAM fit to total CPUE during the post-rationalized period in the WAG.

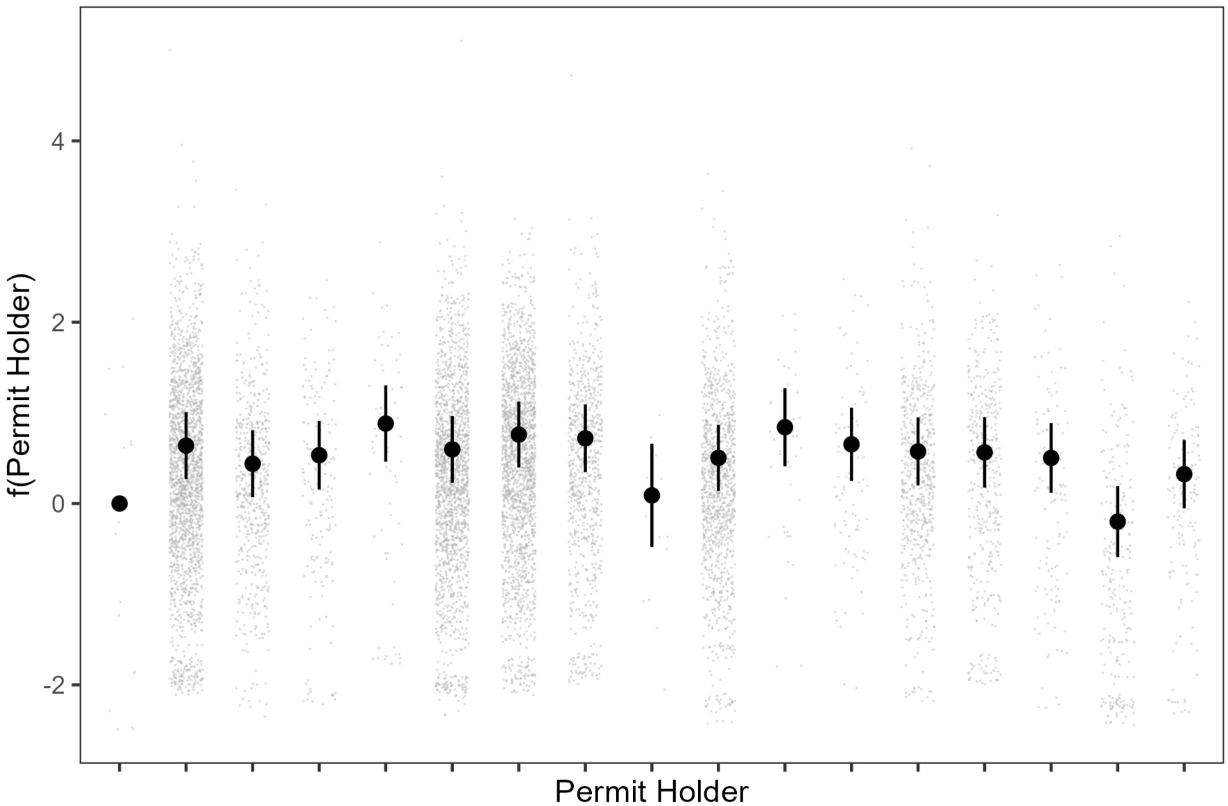

Figure 38: Marginal effects of permit holder with associated partial residuals for the final model fit to total CPUE during post-rationalized period in the WAG.

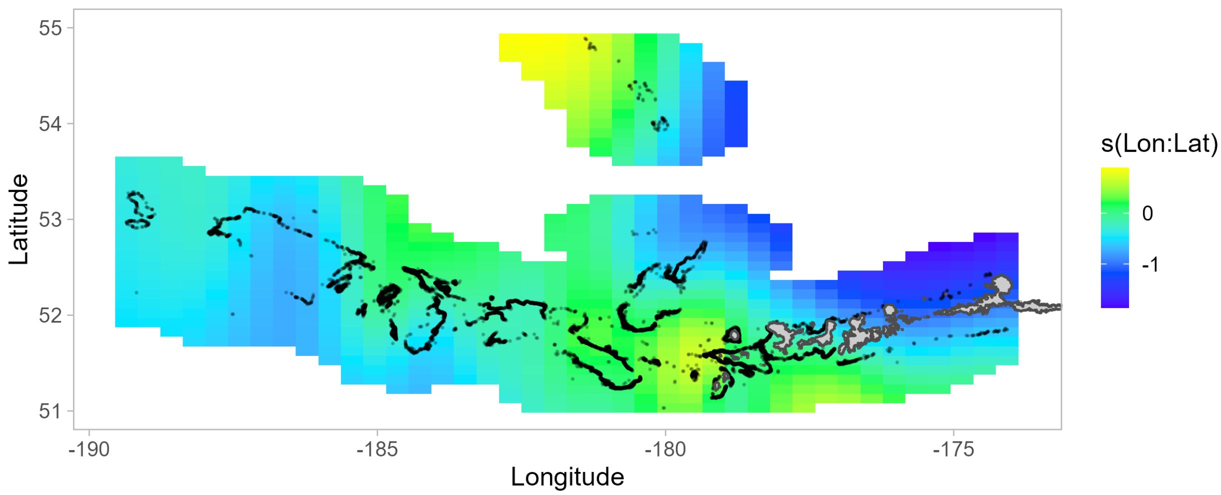

Figure 39: Marginal effects of the two-dimensional smooth of latitude and longtide with associated partial residuals (i.e. pot locations) for the final model fit to total CPUE during post-rationalized period in the WAG.

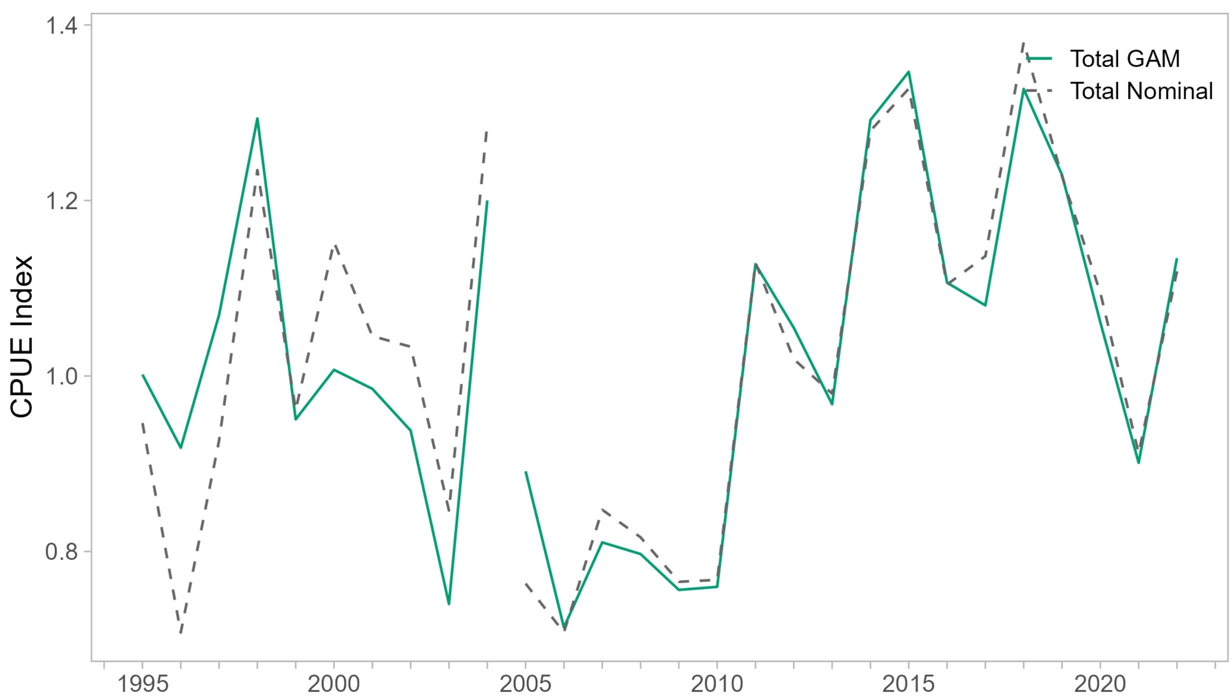

Figure 40: Time series of standardized total CPUE indices estimated for the EAG.

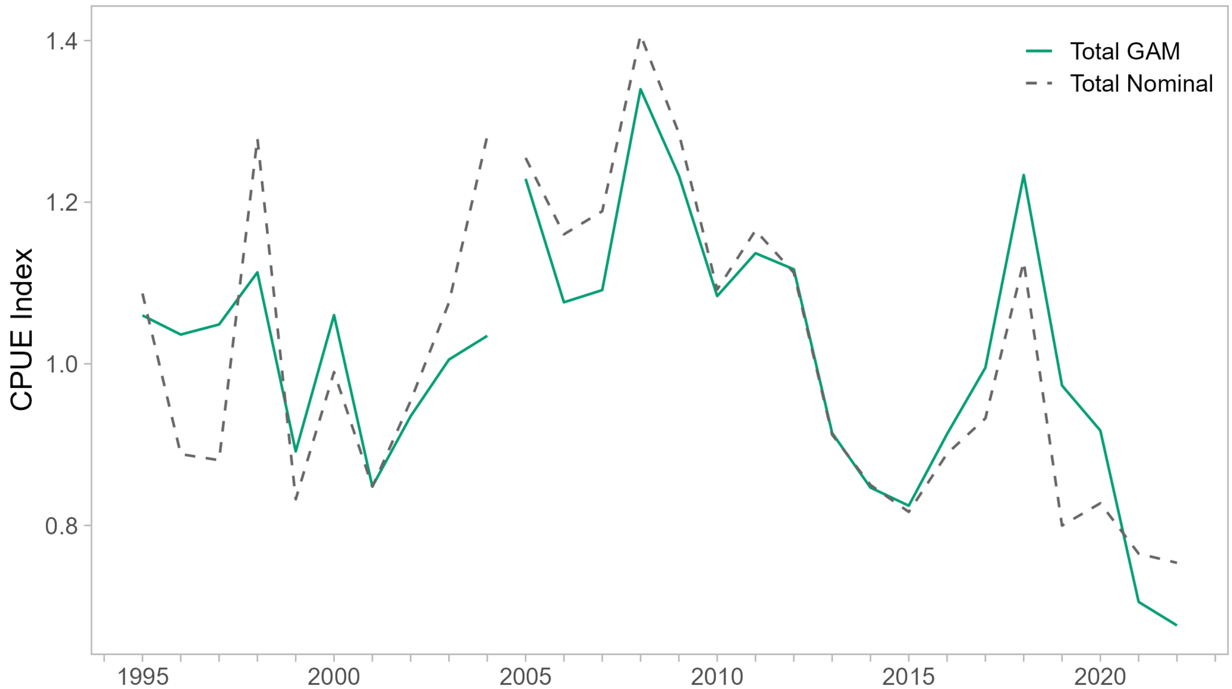

Figure 41: Time series of standardized total CPUE indices estimated for the WAG.

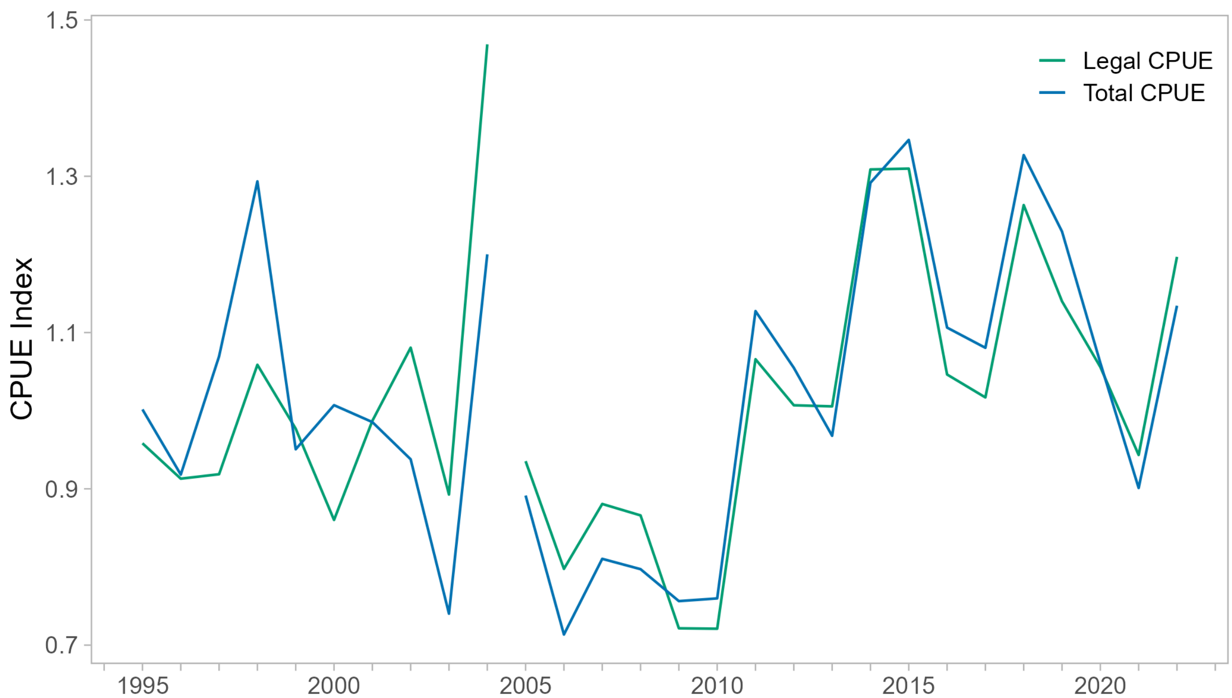

Figure 42: Time series of standardized legal and total CPUE indices estimated for the EAG.

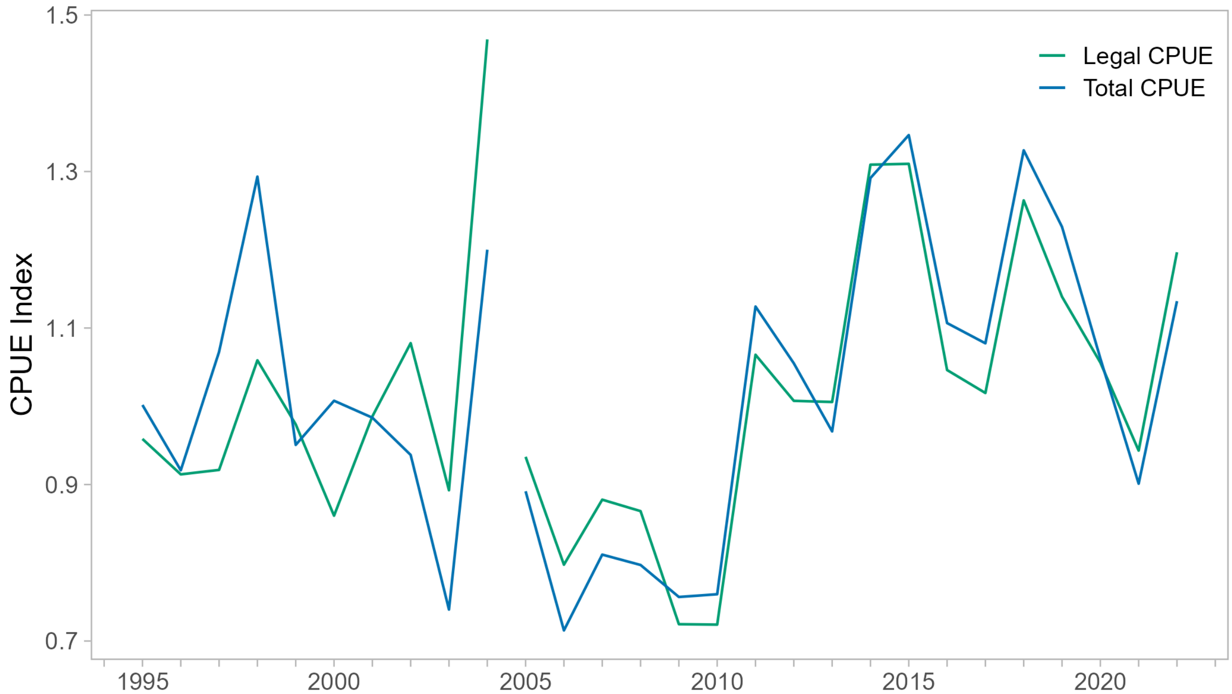

Figure 43: Time series of standardized legal and total CPUE indices estimated for the WAG.

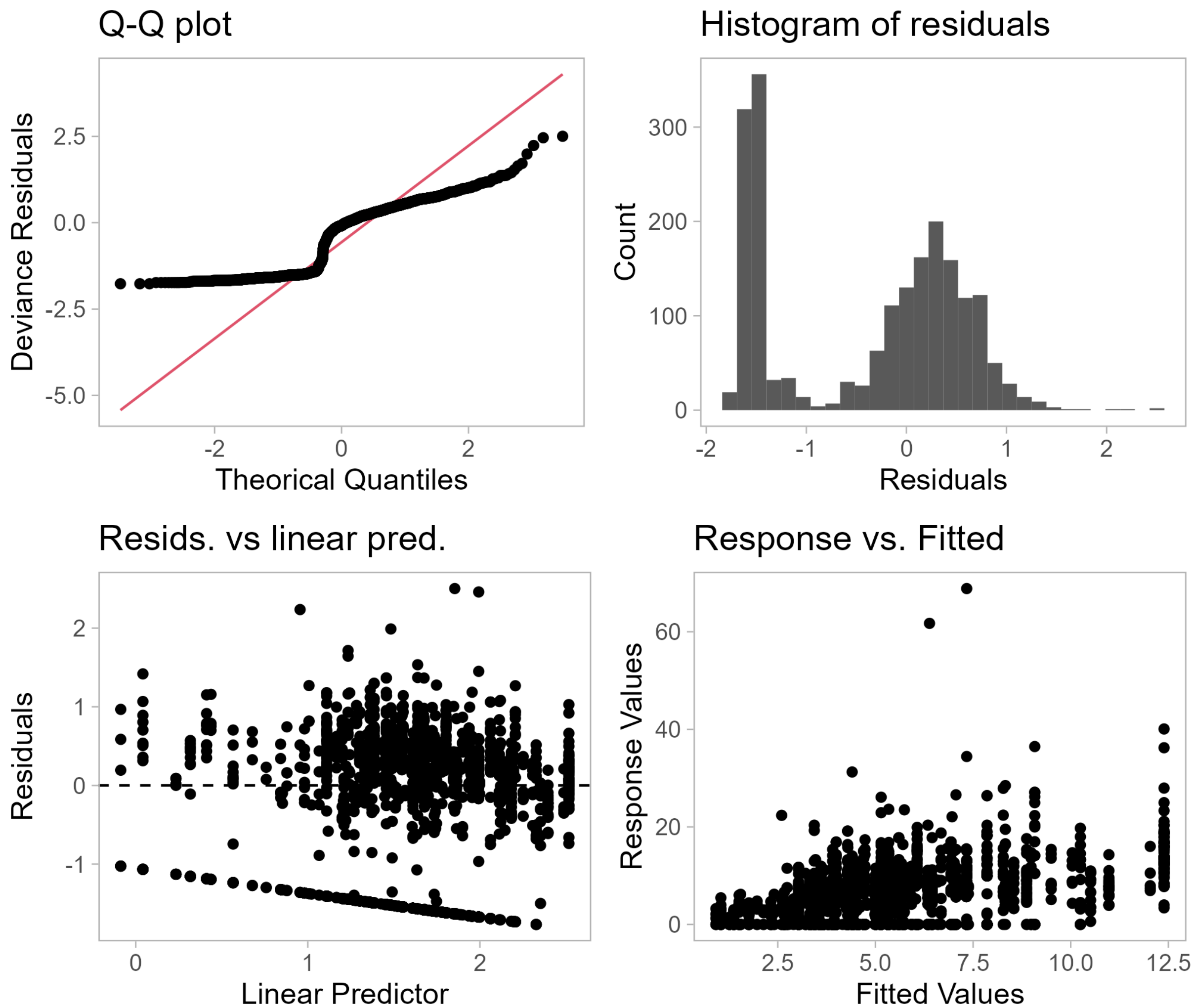

Figure 44: Diagnostic plots for the best model fit to 1985 - 1998 fish ticket CPUE in the EAG.

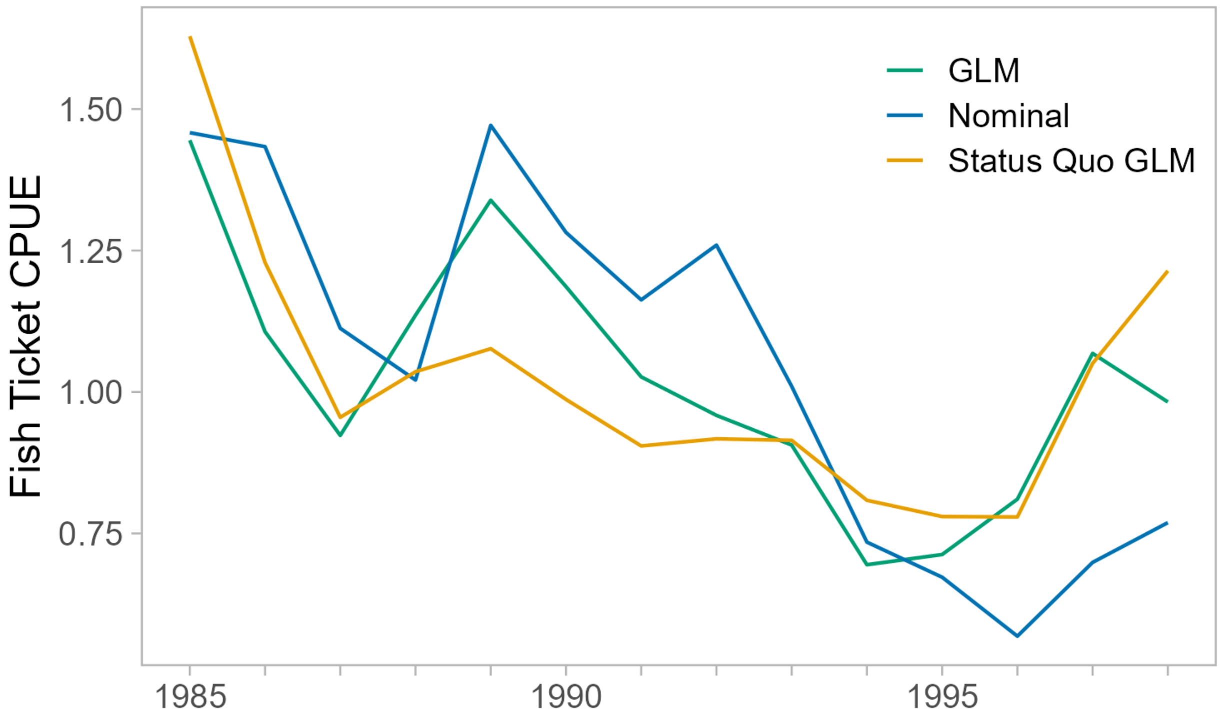

Figure 45: Time series (1985 - 1998) of nominal and standardized fish ticket CPUE indices estimated for the EAG.

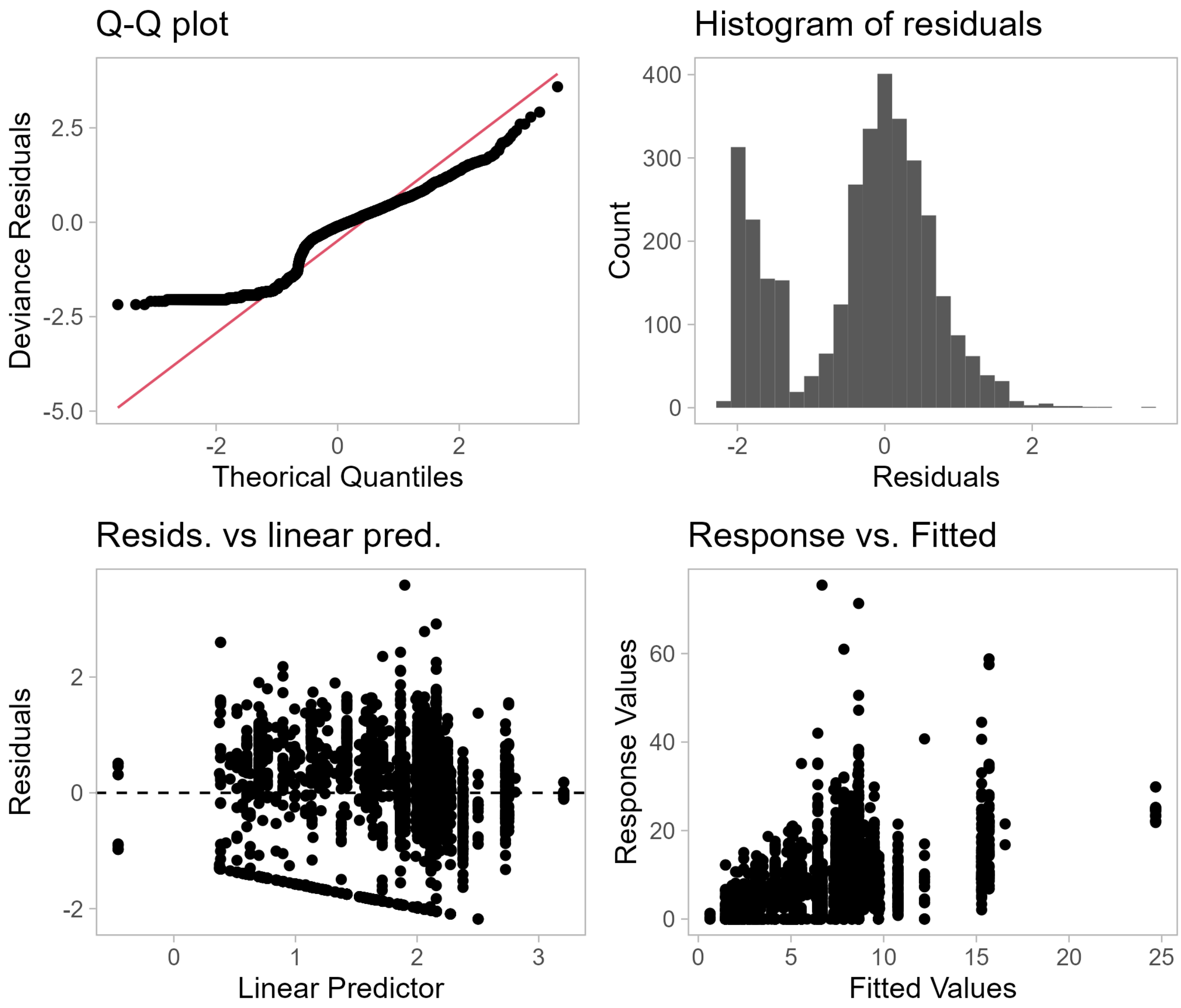

Figure 46: Diagnostic plots for the best model fit to 1985 - 1998 fish ticket CPUE in the WAG.

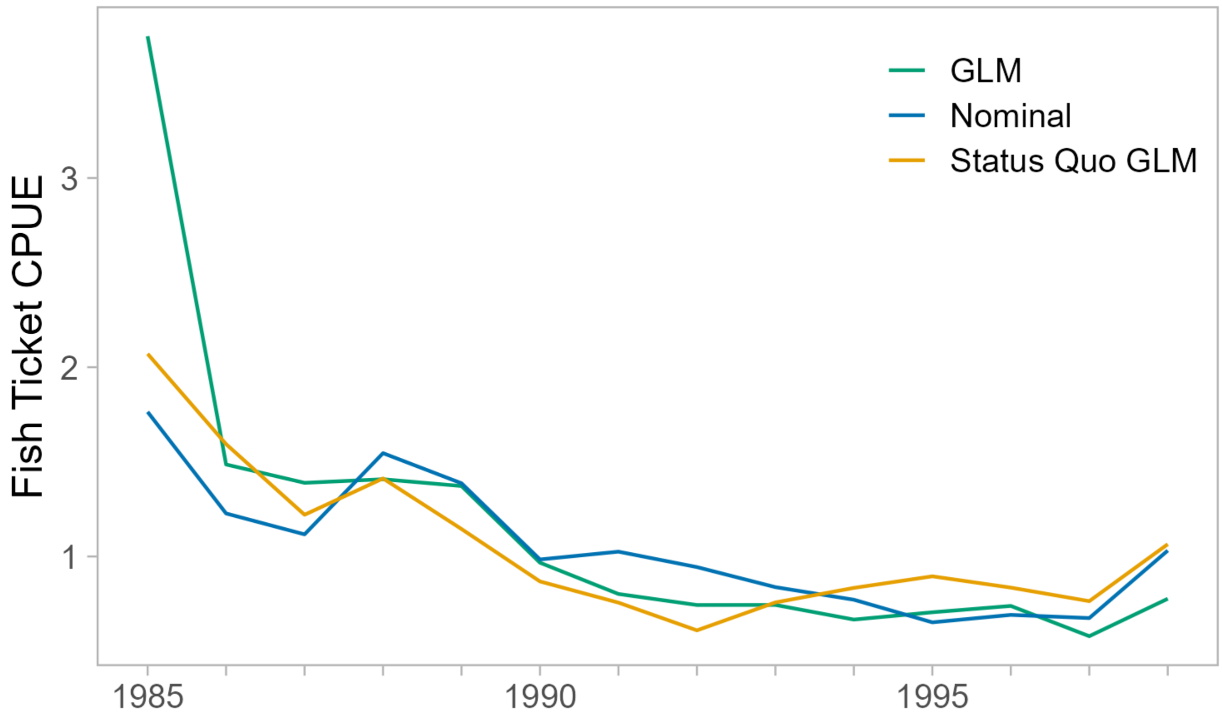

Figure 47: Time series (1985 - 1998) of nominal and standardized fish ticket CPUE indices estimated for the WAG.

Literature Cited

Bozdogan, H. 1987. Model selection Akaike's information criterion (AIC): The general theory and its analytical extensions. Psychometrika 52: 345-370.

Burnham, K.P. and D.R. Anderson. 2002. Model selection and multimodal inference: A practical information-theoretic approach. 2nd edn. Springer-Verlag, New York. 488 pp.

Redlands, C. E. S. R. I. (2011). ArcGIS Desktop: Release 10.

Siddeek, M.S.M., J. Zheng, and D. Pengilly. 2016. Standardizing CPUE from the Aleutian Islands golden king crab observer data. Pages 97–116 in T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks, Alaska.

Siddeek, M.S.M., B. Daly, and T. Jackson. 2023. Aleutian Islands golden king crab stock assessment. North Pacific Fishery Management Council, Anchorage, Alaska.

Venables, W.N. and B.D. Ripley. 2002. Modern Applied Statistics with S, Fourth edition. Springer, New York. ISBN 0-387-95457-0, https://www.stats.ox.ac.uk/pub/MASS4/.

Wood, S. 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. Journal of the American Statistical Association 99: 673-686.

Zimmermann, M., M.M. Prescott, and C.N. Rooper. 2013. Smooth Sheet Bathymetry of the Aleutian Islands. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-250, 43p.

Appendix C: AIGKC Cooperative Pot Suvrey

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Background

The AIGKC cooperative pot survey was initiated in 2015 in the EAG and has continued every year since with the exception of 2020. The survey was extended to WAG in 2018. The main purpose of the survey is to generate a cost effective data stream available to the stock assessment that is spatially representative and less susceptible to hyperstability than fishery catch-per-unit-effort (CPUE). The survey has occurred during the beginning of each season, with participating vessels setting pots strings at pre-determined stations and later picking strings with ADF&G staff on board for collection of biological data. Survey data is available for 2015 - 2022 in the EAG and 2018 and 2019 in the WAG. Since only two years of data are available for the WAG, this appendix only details the preparation of assessment model inputs for the EAG.

Methods

Station Selection and Sampling

The survey area in the EAG consists of a 2x2 nmi grid overlaying the full range of historically fished areas. The survey grid is divided into strata to improve spatial representation. Strata have varied over the time series depending on the vessels participating, but since 2022 the survey design has included three strata (Figure 1). Vessels divided sampling efforts based on their respective fishing grounds. Survey data pre-2022 were stratified to the current design *post hoc*.

Grid cells were randomly selected among strata, and selections were removed or reallocated as necessary to avoid gear conflicts with groundfish trawl operations. The number of selected cells has varied by year. Since 2022 the initial selection process in the EAG included 25 grid cells per stratum. Vessels set pot strings intersecting grid cells at their digression and there are no specific requirements on string length or soak time (Figure 2). Biologists systematically sampled 5-7 pots per string, not beginning or ending on the first or last pot of a string. Due to logistical constraints, not all survey strings were sampled during biologist crewed trips.

Carapace lengths (CL) were recorded for legal and sublegal males, as well as females. Unmeasured crab were counted to obtain a catch number per size-sex catagory for each pot. On deck sampling procedure varied among vessels and crew as working conditions allowed, though biologists targeted CL records from at least ~ 30 crab per pot, with at least 10 of which being legal males. Females were given lowest priority and subsampled at a high rate. Sampling statistics from 2015 - 2022 are detailed in Table 1.

Survey CPUE

Nominal survey CPUE (U_y) was computed as

$$U_y = \frac{1}{k}\sum_{h=1}^{k} U_h \tag{1}$$

$$U_h = \frac{1}{n_h}\sum_{i=1}^{n} U_{i,h} \tag{2}$$

$$U_i, h = \frac{1}{m_i}\sum_{j=1}^{m} U_{j,i} \tag{3}$$

where

U_h = CPUE of stratum h of k;
$U_{i,h}$ = CPUE of string i of n, within stratum h; and
$U_{j,i}$ = CPUE of pot j of m, within string i.

Variance in U_y ($\sigma^2_{U_y}$) was estimated as

$$\sigma^2_{U_y} = \frac{1}{k^2}\sum_{h=1}^{k} \sigma^2_{U_h} \tag{4}$$

$$\sigma^2_{U_h} = \frac{1}{n^2}\sum_{i=1}^{n} \sigma^2_{U_i} \tag{5}$$

Model based CPUE was estimated by a general additive mixed model in the form of

$$\ln(U_j) = \text{Year}_y + s(\text{soak time}) + (1|\text{Stratum}_h/\text{String}_{i,y}) + \epsilon \tag{6}$$

in which ϵ is negative binomial distributed error with $\theta = 1.318$. The annual CPUE index was extracted from model results following the same method as used for observer CPUE standardization (Appendix B).

Results

Model diagnostics indicate an adequate fit to the data (Figure 3). The marginal effect of soak time (EDF = 4.11) suggested a slow positive increase followed by a sharp decline at the largest values (i.e., roughly at 25 days) (Figure 4). The resulting index follows a similar trend to the nominal CPUE, though with a more apparent decrease over the survey time series (Figure 5).

The CPT (2018) recommended to standardize cooperative survey data using models that represents the nested sampling design. The standardization method proposed here accounts for varying soak time with respect to the survey design. Vessel and captain were not used to standardize survey CPUE since vessels have little to no overlap in survey pots (Figure 2), and thus would be confounded with spatial variability associated with strata.

Survey size composition showed little variability in the prominent mode, with most individuals measured between 125 - 175 mm CL. Sublegal males were more abundant in 2015 - 2019 surveys (Figure 6).

Tables

Table 1: Number of strings and pots sampled, total number of male crab measured, and proportion of legal and sublegal crab measured (of total caught per catagory) per survey in the EAG.

				Proportion Measured	
Suvrey Year	Strings Sampled	Pots Sampled	Males Measured	Legal	Sublegal
2015	63	339	5,089	0.34	0.44
2016	62	304	3,998	0.33	0.27
2017	47	212	3,849	0.40	0.33
2018	48	235	3,323	0.26	0.18
2019	47	293	6,190	0.68	0.60
2021	46	298	6,665	0.81	0.85
2022	55	374	10,276	0.72	0.88

Figures

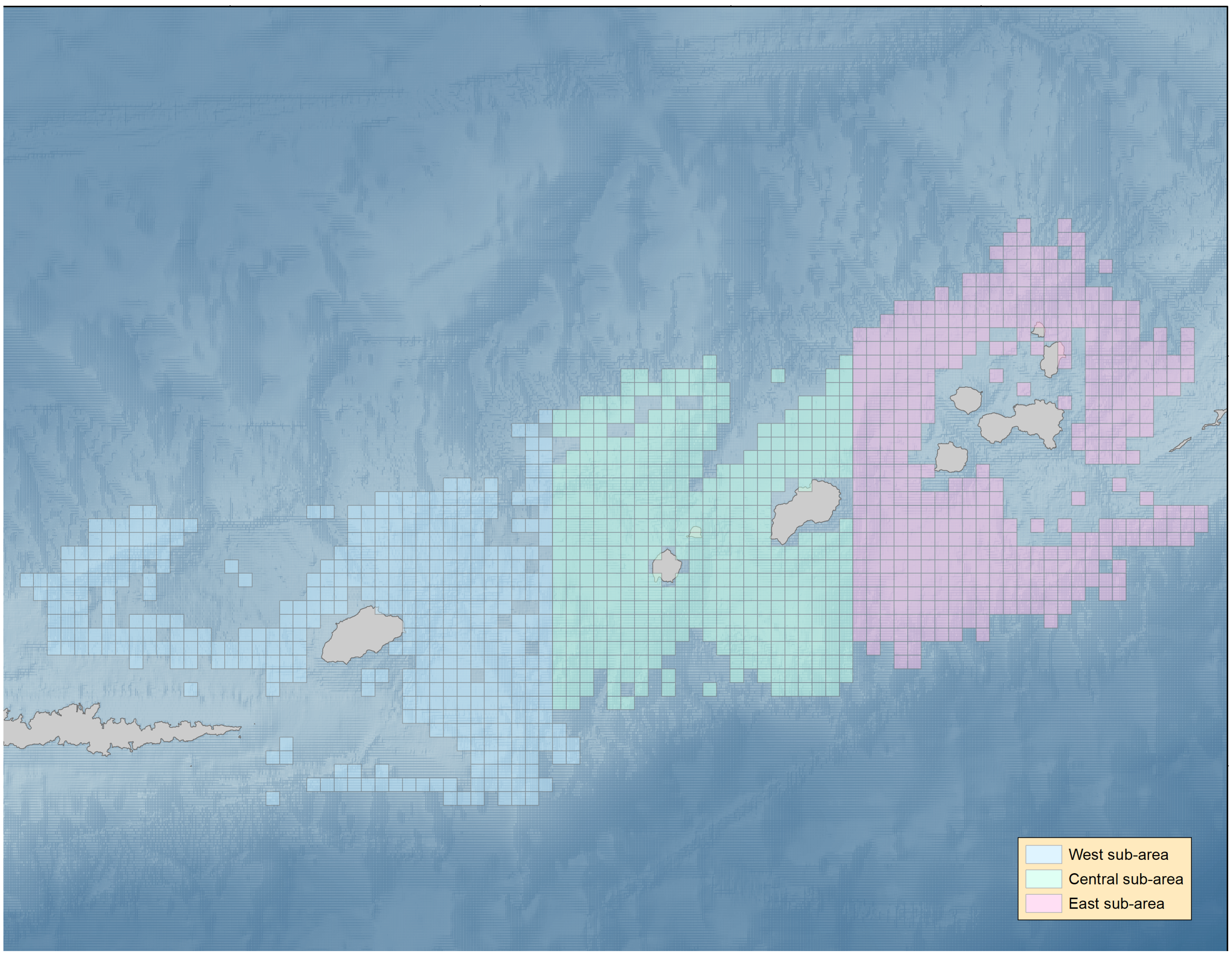

Figure 1: Map of survey grid in the EAG colored by stratum.

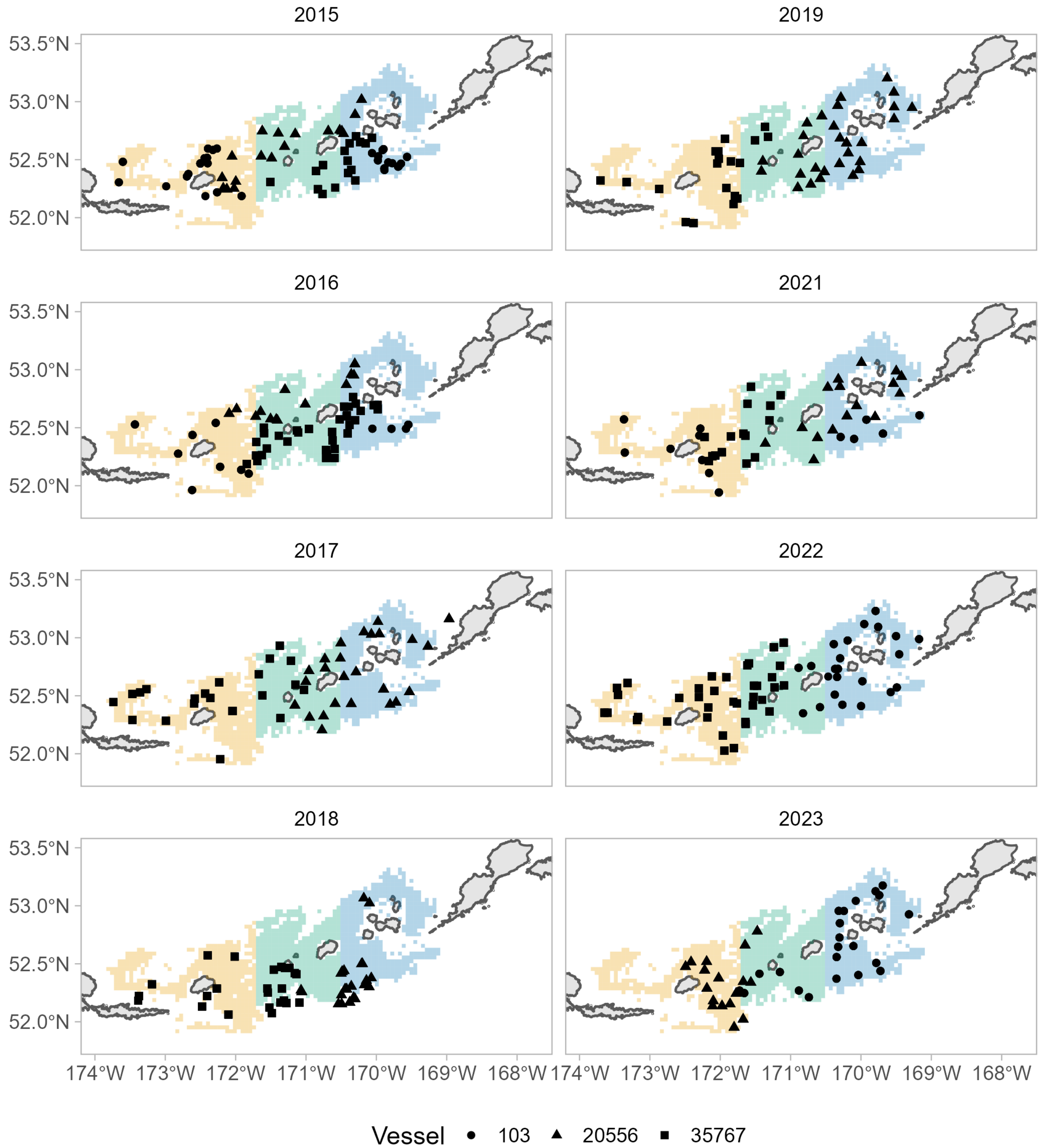

Figure 2: Map of stings sampled in the EAG by survey year.

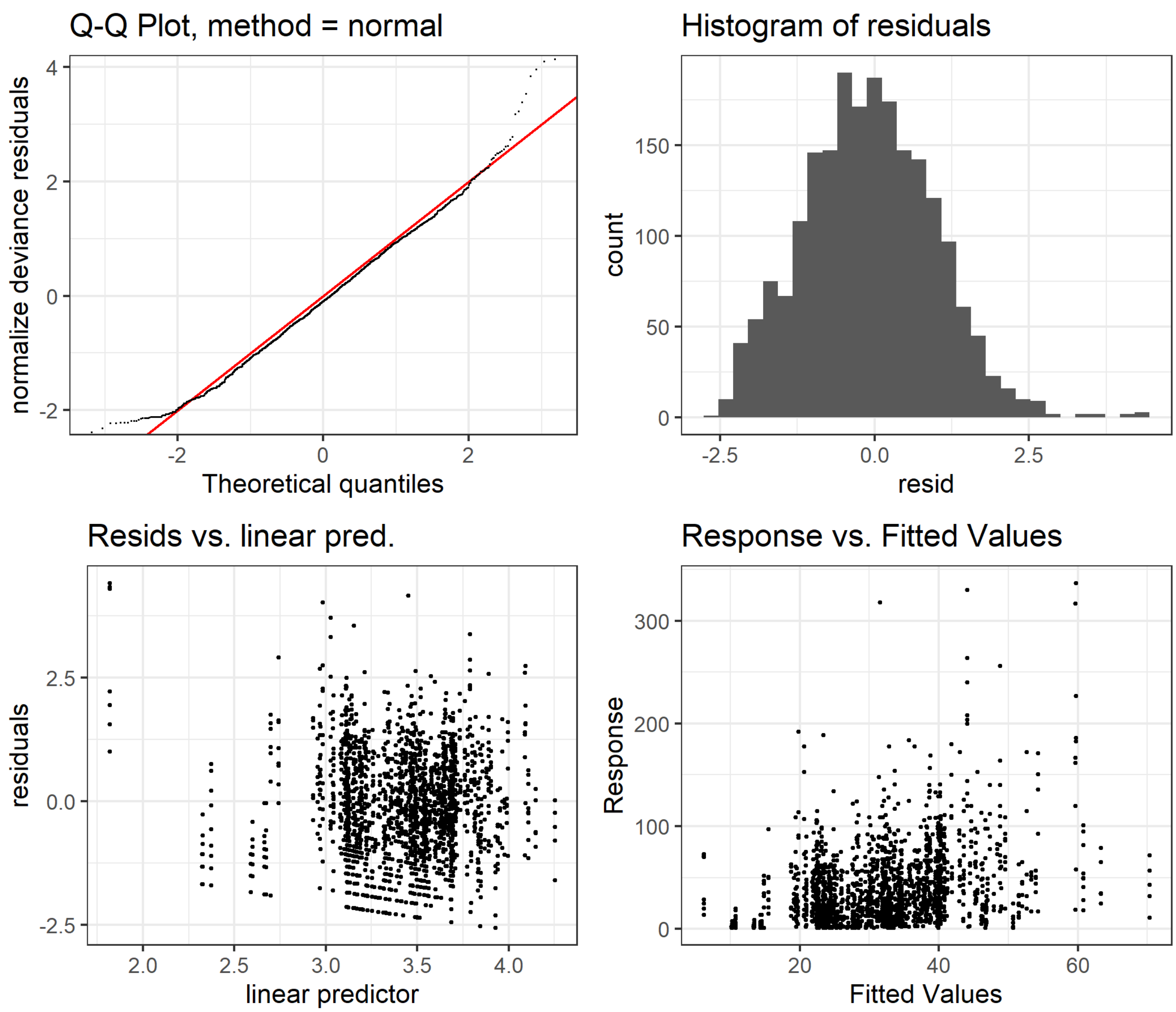

Figure 3: Diagnostic plots for the GAMM fit to survey in the EAG.

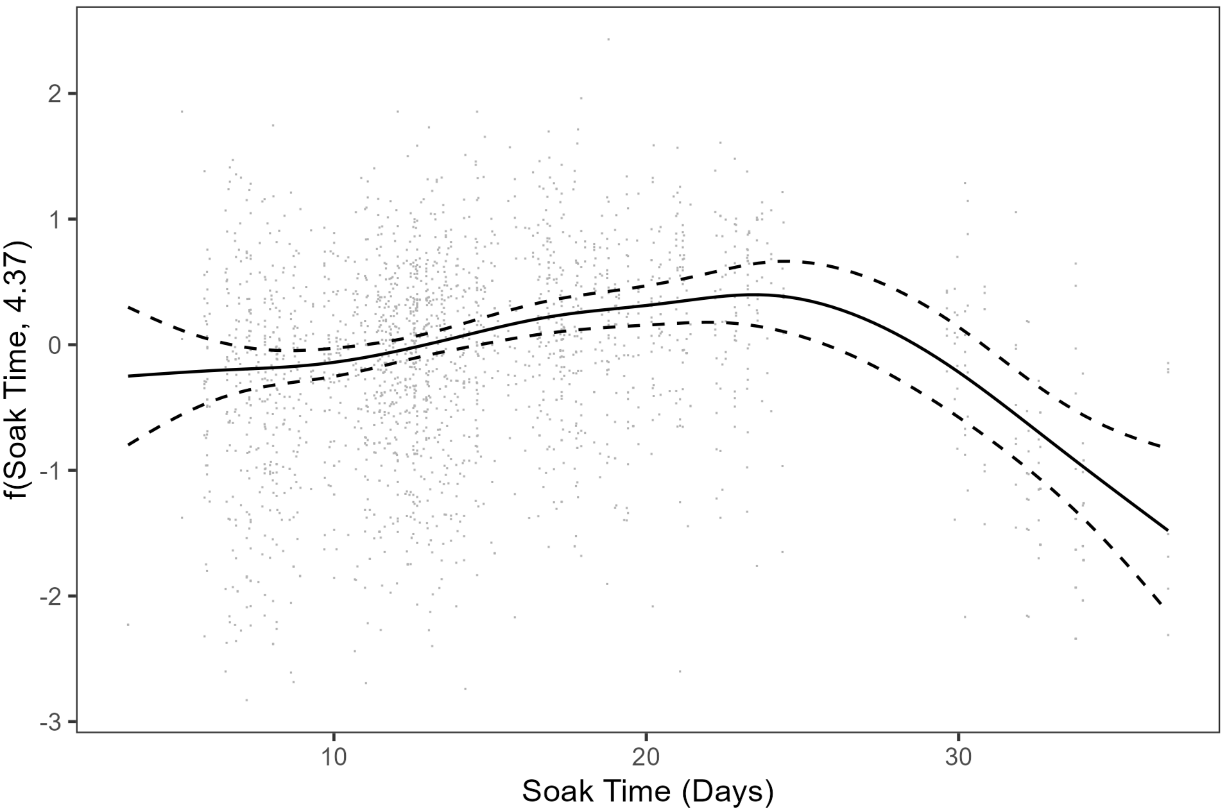

Figure 4: Marginal effect of soak time with associated partial residuals for the GAMM fit to survey CPUE in the EAG.

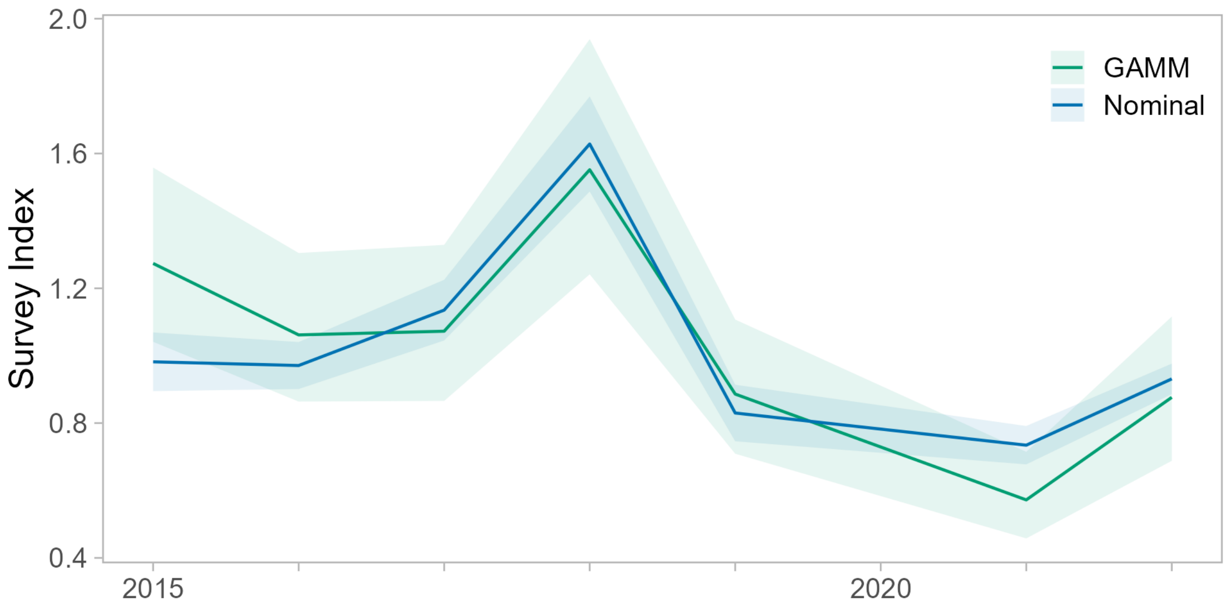

Figure 5: Time series of standardized survey CPUE indices estimated for the EAG.

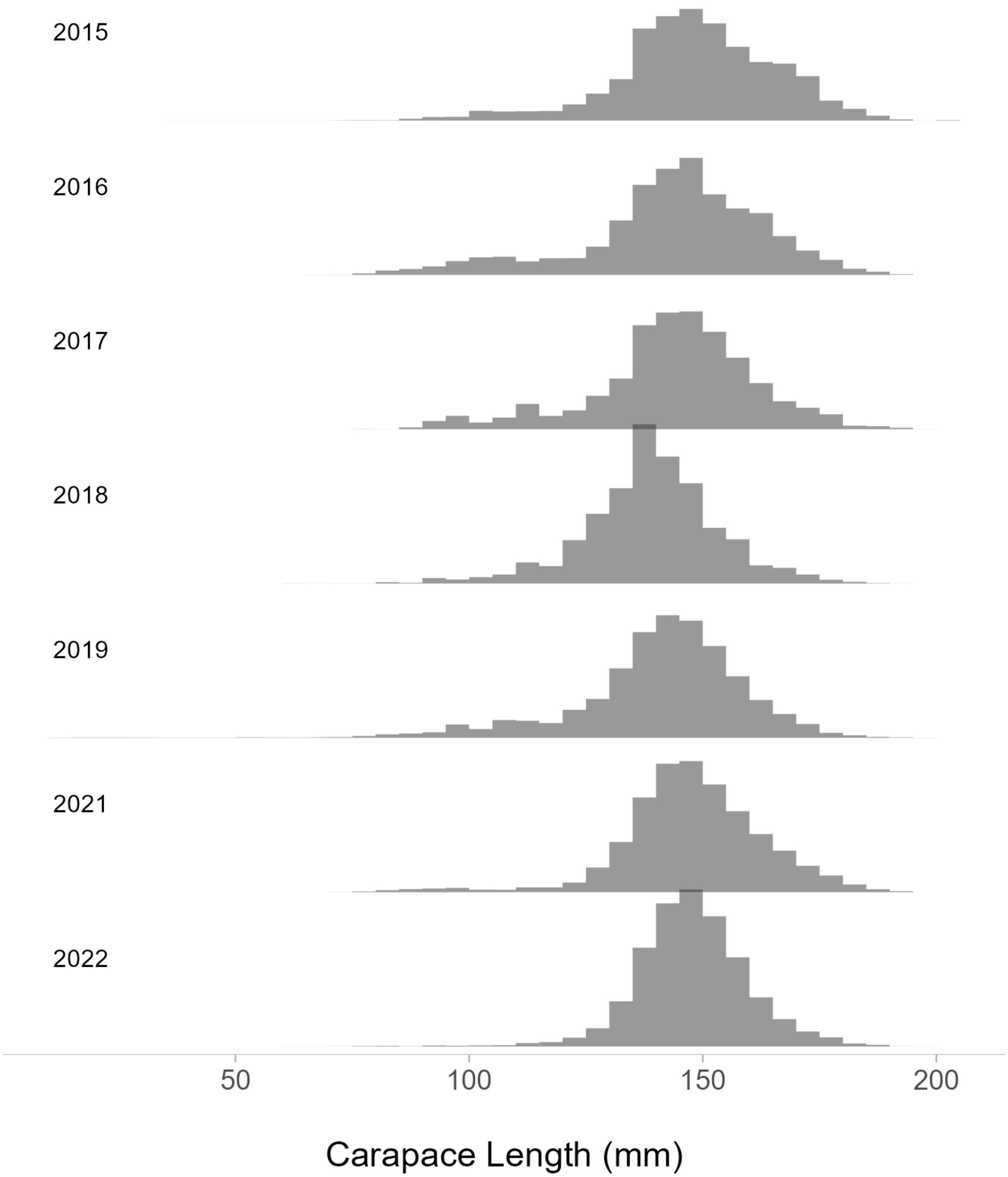

Figure 6: Time series of carapace length composition estimated for the EAG.