Abundance indices of Swordfish (*Xiphias gladius*) by the Japanese offshore and distant-water longline fishery in the North-Western Central Pacific

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Abstract

The area-separated standardized CPUE of swordfish caught by Japanese longliners in the Western and central North Pacific Ocean between 1994 and 2016 were provided. In area 1, the Northwest Pacific area, CPUE declined in the early period and increased in the late period. In area 2, the Northern central Pacific area, there was a continuous increasing trend in CPUE.

The area-separated standardized CPUEs between 1975 and 1993 in both area 1 and 2 were provided. The standardization model that was applied to CPUE data in the late period did not converge when applied to the early data. Therefore a simpler CPUE standardization model was applied to the early period CPUE data. While there were no issues for the early CPUE model diagnostics, the amount of residual deviance that was explained by the model in area 2 was low.

Introduction

The abundance indices are one of the most fundamental information of stock assessment. The annual trend of the Catch per unit effort (CPUE) is one of the common indices to show the trend of stock abundance and is required to remove the effect relating with fishing efficiency. Therefore, standardization of CPUE is required. . The purpose of this document is to provide the optimal abundance indices by using Japanese longline data for swordfish in North Western Central Pacific.

Materials and Methods

In this study, set by set data including year, season and gear configurations between 1994 and 2016 were used for the analysis. The operation area was separated by the same definition with Ichinokawa and Brodziak (2010) and Ijima and Kanaiwa (2018) (Fig. 1). In this analysis, we focused only area 1 and 2, i.e. in the North-Western Central Pacific. The gear configurations was separated to 0) 3-5 and 1) >6 HPB. Data of sets with its HPB is smaller than 2 or larger than 23 were excluded from the analysis. All data number for each area was shown in Table 1.

The standardized model was conducted as the following equation.

number of caught sword fish~ year + quarter + gear + lat + lon + offset(log(hooks)) + poisson error. As the model, we used generalized linear model (glm), generalized linear mixture model (glmm) in which the each cruise is set as random effect, generalized additive model (gam) which latitude and longitude are set as 2 dimensional 3 degree spline function and generalized additive mixture model (gamm). The optimal model was selected by BIC.

Results and Discussions

The gamms were selected as optimal models for both areas by BIC (Table 2). The detail of output and residuals pattern was shown in Appendix. The residual deviances decrease 65.4% and 39.0% for each area, respectively (Table 3). Scaled standardized CPUE by each model was shown in Fig. 2 and there were three patterns of trend i.e. nominal, glm and gam, and glmm and gamm, for both areas. The trends of glmm and gamm were more smooth than others. Therefore we concluded that the optimal models are significant. However, there were some issues about residual's pattern in gamm for area 1 (Appendix1). The standardization without deep set was conducted and the residual's pattern looks better than with deep set and the annualt trend does not have big difference (Appendix 2).

References

Ichinokawa, M. and J. Brodziak 2010. Using adaptive area stratication to standardize catch rates with application to north pacific swordfish (*xiphias gladius*). Fisheries Research 106 (3), 249-260.

Ijima, H. and M. Kanaiwa. 2018. Pattern recognition of population dynamics for North Pacific swordfish (Xiphias gladius) : the operational data analysis of Japanese longline fishery using the finite mixture model. ISC/8/BILLWG-01/XX. 12pp.

Table 1. The no of set for each category

a) area 1

	season				HPB		
year	0	1	2	3	0	1	Total
1994	5,695	7,305	4,940	6,868	7,945	16,863	24,808
1995	4,885	7,340	5,656	5,626	7,708	15,799	23,507
1996	4,263	7,382	5,154	4,212	7,506	13,505	21,011
1997	3,462	7,328	4,862	4,447	7,114	12,985	20,099
1998	3,967	7,402	4,700	4,171	7,053	13,187	20,240
1999	3,566	6,948	4,175	4,312	7,142	11,859	19,001
2000	3,393	6,895	3,508	4,439	7,821	10,414	18,235
2001	3,405	7,659	4,048	4,153	7,776	11,489	19,265
2002	3,271	6,808	3,837	3,539	6,920	10,535	17,455
2003	3,294	5,855	4,437	4,836	5,867	12,555	18,422
2004	3,406	5,160	3,746	4,083	5,624	10,771	16,395
2005	2,799	4,903	3,407	3,573	5,200	9,482	14,682
2006	2,356	3,829	2,231	3,696	4,984	7,128	12,112
2007	2,924	3,240	2,496	4,023	5,708	6,975	12,683
2008	2,863	3,335	2,205	3,255	5,155	6,503	11,658
2009	2,785	2,822	1,766	2,563	4,506	5,430	9,936
2010	2,388	2,947	1,571	2,644	3,972	5,578	9,550
2011	2,339	2,520	2,030	2,875	2,348	7,416	9,764
2012	2,386	3,089	1,813	2,872	2,881	7,279	10,160
2013	2,650	3,435	2,065	3,084	3,170	8,064	11,234
2014	2,375	3,231	1,636	2,708	3,134	6,816	9,950
2015	2,212	3,003	1,619	2,620	2,607	6,847	9,454
2016	2,743	3,284	1,705	2,954	2,535	8,151	10,686

b) area 2

	season				HPB		
year	0	1	2	3	0	1	Total
1994	17,200	11,553	12,083	13,393	96	54,133	54,229
1995	13,823	11,812	10,429	11,322	138	47,248	47,386
1996	12,337	9,804	7,763	8,888	84	38,708	38,792
1997	9,759	9,077	7,738	7,062	74	33,562	33,636
1998	7,401	7,254	10,030	10,055	3	34,737	34,740
1999	9,902	8,452	9,411	10,932	0	38,697	38,697
2000	11,309	9,722	10,098	8,349	4	39,474	39,478
2001	10,195	8,992	9,125	9,535	11	37,836	37,847
2002	10,922	10,318	10,384	8,904	43	40,485	40,528
2003	9,764	8,865	8,421	8,617	154	35,513	35,667
2004	9,012	7,711	7,341	6,393	607	29,850	30,457
2005	8,124	6,318	6,650	5,220	169	26,143	26,312
2006	6,819	6,564	6,227	5,385	145	24,850	24,995
2007	6,358	5,646	5,337	3,921	172	21,090	21,262
2008	4,646	5,701	5,079	4,632	165	19,893	20,058
2009	5,502	4,509	4,571	4,553	82	19,053	19,135
2010	5,595	5,842	5,937	6,402	219	23,557	23,776
2011	5,758	5,358	5,154	5,755	8	22,017	22,025
2012	4,523	5,445	5,579	5,374	19	20,902	20,921
2013	3,912	4,702	4,805	3,315	0	16,734	16,734
2014	3,189	3,229	4,406	3,604	0	14,428	14,428
2015	3,196	3,069	2,350	2,009	0	10,624	10,624
2016	2,436	2,572	1,870	1,449	0	8,327	8,327

Table 2. BIC for each model

Model	BIC of A1	BIC of A2
glm	1865825	648473
glmm	1360874	580212
gam	1755325	620910
gamm	1341327	570811

Table 3. Residuals deviances

	Area 1	Area2
Null residuals deviance	2093902	575675
Optimal residuals deviance	724076	368655

Table 4. Nominal CPUE, standardized CPUE and standard error for each region.

	Area 1			Area 2		
year	nCPUE	sCPUE	SE	nCPUE	sCPUE	SE
1994	1.2846	1.3705	0.0289	0.1260	0.0946	0.0327
1995	1.1200	1.3144	0.0260	0.1108	0.0908	0.0304
1996	1.2561	1.1938	0.0263	0.1322	0.1102	0.0304
1997	1.2154	1.0889	0.0275	0.1097	0.0803	0.0325
1998	1.0596	1.0497	0.0278	0.1029	0.0821	0.0319
1999	0.9717	0.9942	0.0285	0.1142	0.1120	0.0306
2000	1.1283	0.9522	0.0284	0.1376	0.1268	0.0303
2001	0.9376	1.0610	0.0289	0.1576	0.1357	0.0311
2002	1.0102	0.8360	0.0293	0.1522	0.1152	0.0319
2003	0.8035	0.8461	0.0284	0.1466	0.1118	0.0339
2004	0.9789	0.8109	0.0276	0.2561	0.0999	0.0350
2005	1.1670	0.8231	0.0271	0.1635	0.0890	0.0373
2006	1.3819	0.8830	0.0268	0.2039	0.1078	0.0366
2007	1.3311	0.8541	0.0271	0.1999	0.1032	0.0383
2008	0.9904	0.7724	0.0292	0.2084	0.1301	0.0384
2009	1.1997	1.0455	0.0317	0.1477	0.1278	0.0402
2010	1.1169	0.8670	0.0324	0.1725	0.1051	0.0416
2011	0.9166	0.7369	0.0325	0.1319	0.1243	0.0440
2012	0.9128	0.8472	0.0318	0.1491	0.1249	0.0455
2013	0.9057	0.7716	0.0321	0.1334	0.1201	0.0481
2014	0.9922	0.9665	0.0325	0.1461	0.1084	0.0520
2015	1.1879	1.0840	0.0329	0.1747	0.1261	0.0588
2016	1.1111	0.9690	0.0375	0.2033	0.1260	0.0700

Table 5 The Pearson product-moment correlation coefficient between nominal and standardized CPUEs

Area 1	Area 2
0.447343	0.259251

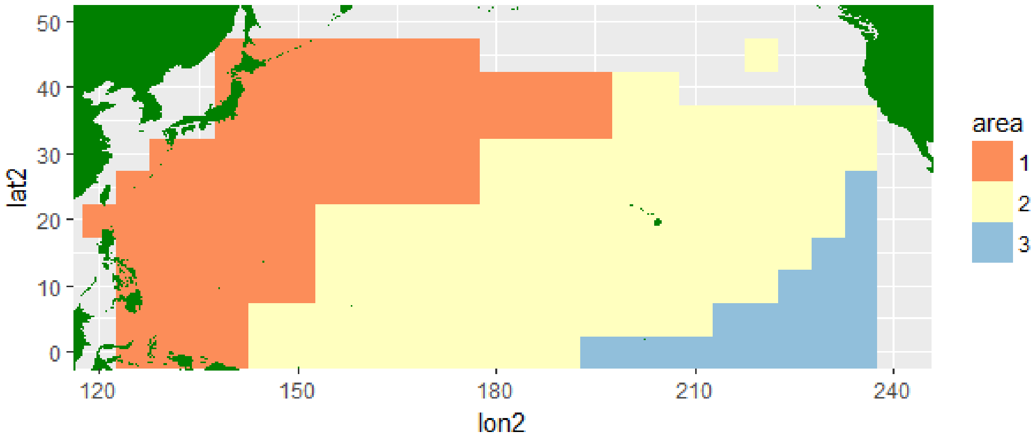
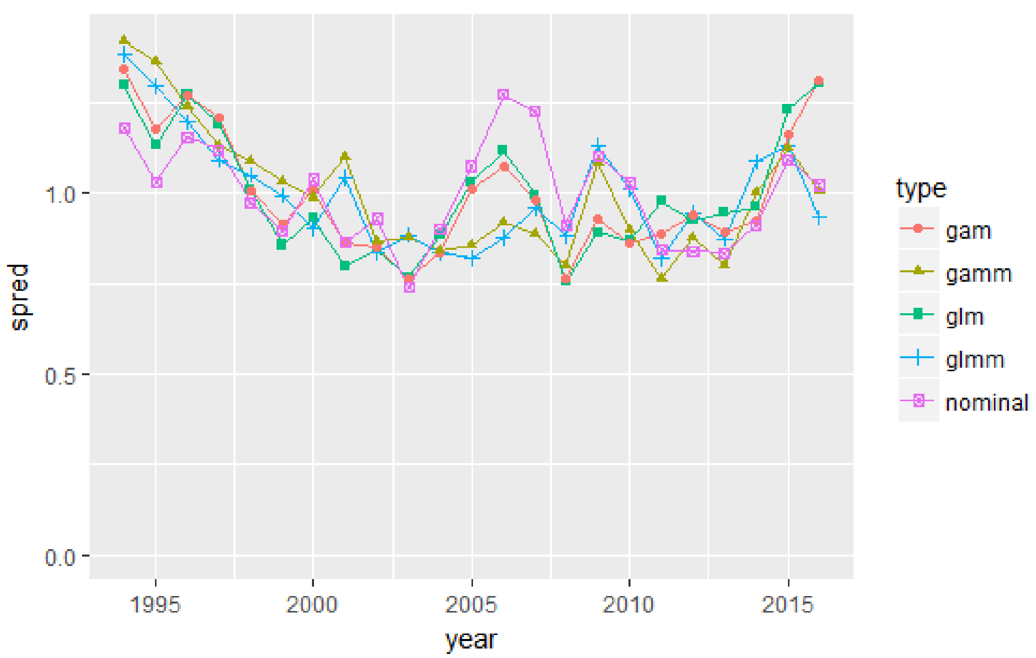


Figure 1. Area stratifications in the WCNPO and the EPO, adapted from Ichinokawa and Brodziak (2010) and Ijima and Kanaiwa (2018), used for this analysis.

a) Area 1



b) Area 2

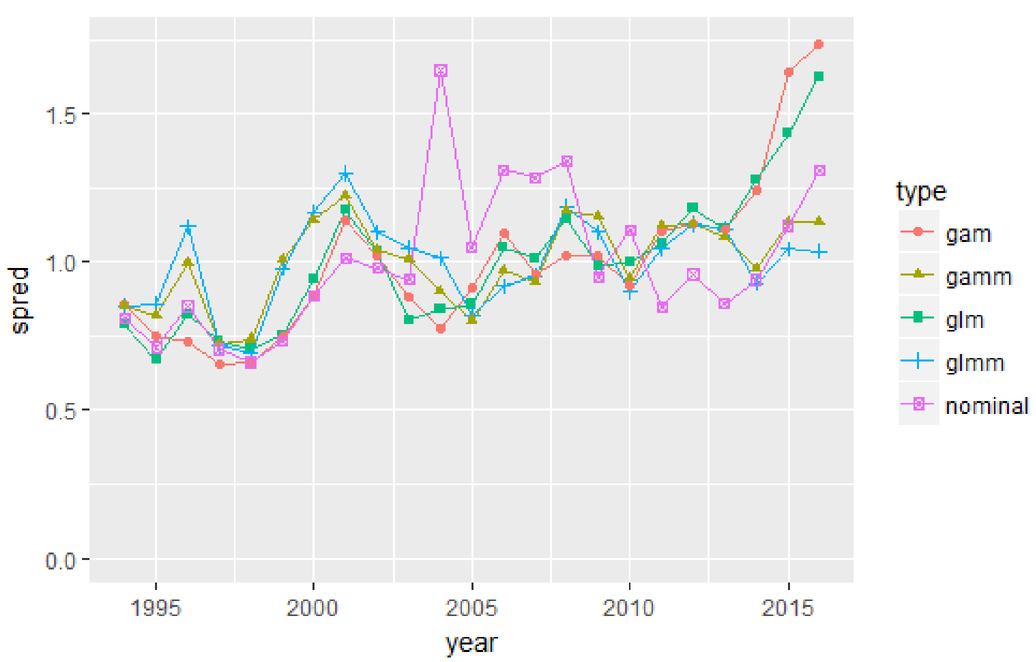
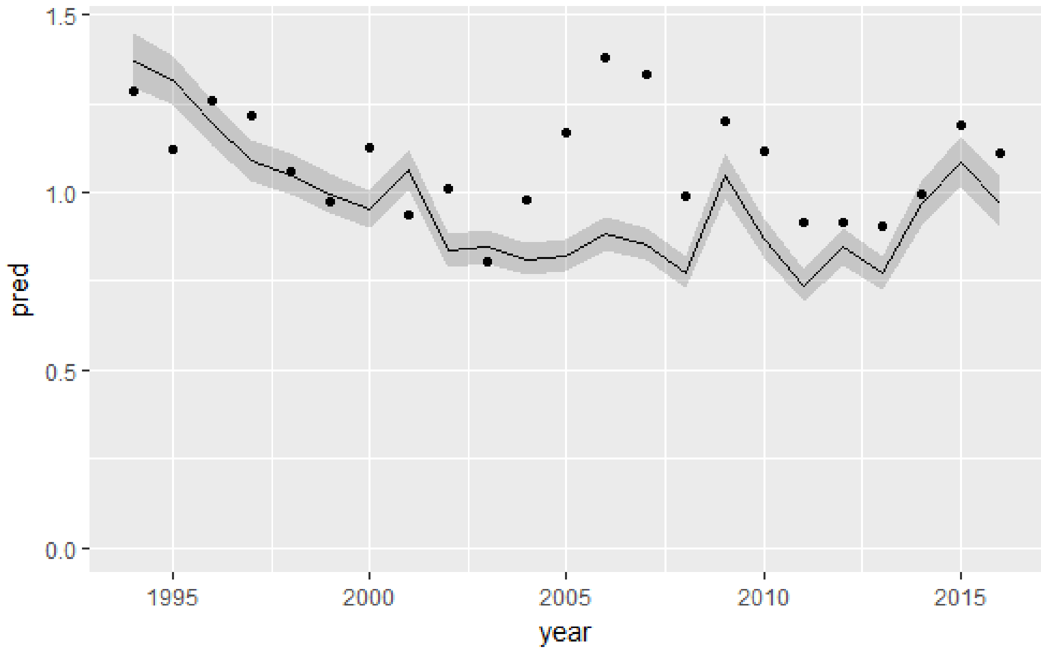


Figure 2. Scaled nominal and standardized CPUE for each area.

a) Area 1



b) Area 2

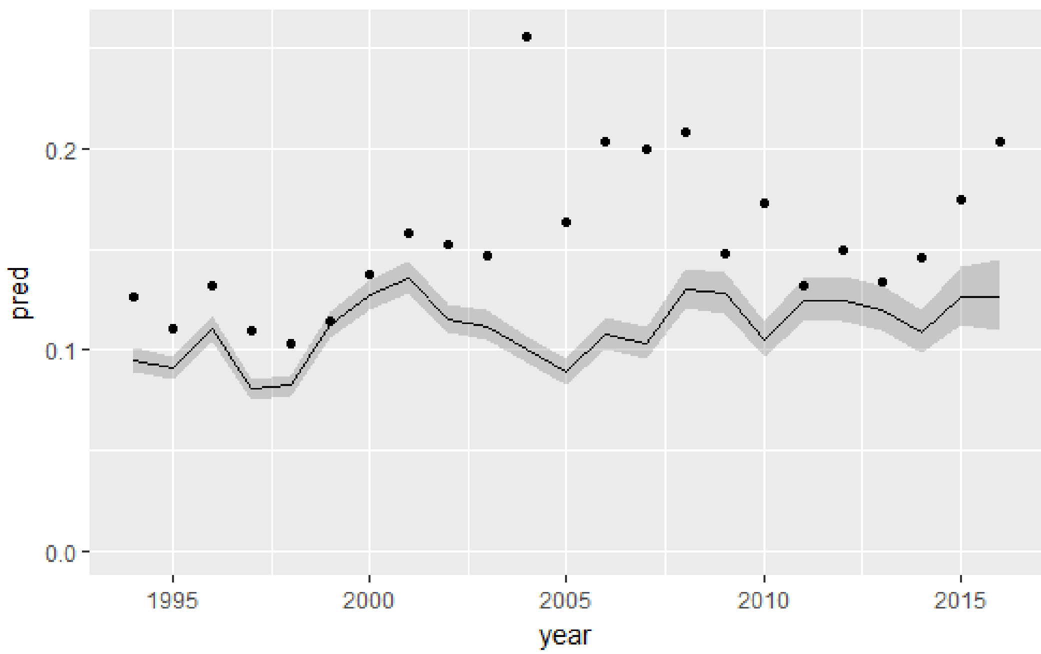


Figure3. Optimal standardized CPUE and nominal CPUE for each area. For area1, the estimated standardized CPUE is calculated when quarter is 1st and hpb is shallower and for area 2, it is calculated when quarter is 1st and hpb is deeper.

Appendix 1

Summary of optimal model for area 1

glmm part

```
Generalized linear mixed model fit by maximum likelihood (Laplace
  Approximation) [glmerMod]
 Family: poisson  ( log )

      AIC       BIC    logLik  deviance  df.resid
1340993.0 1341326.7 -670465.5 1340931.0    350276

Scaled residuals:
   Min     1Q Median     3Q    Max
-8.724 -0.774 -0.382  0.490 49.226

Random effects:
 Groups Name        Variance Std.Dev.
 uid    (Intercept)  1.106   1.052
 Xr     s(lat,lon)  22.187   4.710
Number of obs: 350307, groups:  uid, 15138; Xr, 27

Fixed effects:
                      Estimate Std. Error z value Pr(>|z|)
X(Intercept)         -6.719796   0.026713 -251.56  < 2e-16 ***
Xfactor(year)1995 -0.041821   0.027284   -1.53    0.125
Xfactor(year)1996 -0.138050   0.032074   -4.30 1.68e-05 ***
Xfactor(year)1997 -0.230029   0.034896   -6.59 4.35e-11 ***
Xfactor(year)1998 -0.266680   0.035880   -7.43 1.06e-13 ***
Xfactor(year)1999 -0.321017   0.036455   -8.81  < 2e-16 ***
Xfactor(year)2000 -0.364153   0.036563   -9.96  < 2e-16 ***
Xfactor(year)2001 -0.255993   0.036748   -6.97 3.25e-12 ***
Xfactor(year)2002 -0.494276   0.036977  -13.37  < 2e-16 ***
Xfactor(year)2003 -0.482359   0.036197  -13.33  < 2e-16 ***
Xfactor(year)2004 -0.524750   0.035733  -14.69  < 2e-16 ***
Xfactor(year)2005 -0.509933   0.035445  -14.39  < 2e-16 ***
Xfactor(year)2006 -0.439639   0.035544  -12.37  < 2e-16 ***
Xfactor(year)2007 -0.472860   0.036095  -13.10  < 2e-16 ***
```

```
Xfactor(year)2008 -0.573425      0.037706    -15.21    < 2e-16 ***
Xfactor(year)2009 -0.270663      0.039481     -6.86 7.11e-12 ***
Xfactor(year)2010 -0.457888      0.039818    -11.50    < 2e-16 ***
Xfactor(year)2011 -0.620560      0.039838    -15.58    < 2e-16 ***
Xfactor(year)2012 -0.481002      0.039215    -12.27    < 2e-16 ***
Xfactor(year)2013 -0.574449      0.039613    -14.50    < 2e-16 ***
Xfactor(year)2014 -0.349268      0.039630     -8.81    < 2e-16 ***
Xfactor(year)2015 -0.234580      0.040446     -5.80 6.64e-09 ***
Xfactor(year)2016 -0.346707      0.044758     -7.75 9.47e-15 ***
Xfactor(qtr)1         -0.079795      0.006203    -12.86    < 2e-16 ***
Xfactor(qtr)2         -0.089674      0.007051    -12.72    < 2e-16 ***
Xfactor(qtr)3          0.060860      0.006475      9.40    < 2e-16 ***
Xfactor(hpb2)1       -1.546421      0.008763 -176.47    < 2e-16 ***
Xs(lat,lon)Fx1         0.914245      0.040839      22.39    < 2e-16 ***
Xs(lat,lon)Fx2         0.656047      0.030626      21.42    < 2e-16 ***
---
Signif. codes:    0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation matrix not shown by default, as p = 29 > 12.
Use print(x, correlation=TRUE)    or
                 vcov(x)    if you need it
```

gam part

```
Family: poisson
Link function: log

Formula:
swo ~ factor(year) + factor(qtr) + s(lat, lon) + factor(hpb2) +
       offset(log(hooks))

Parametric coefficients:
                                  Estimate Std. Error    z value Pr(>|z|)
(Intercept)           -6.719796      0.028137 -238.826    < 2e-16 ***
factor(year)1995 -0.041821      0.028068      -1.490        0.136
factor(year)1996 -0.138050      0.033138      -4.166 3.10e-05 ***
factor(year)1997 -0.230029      0.036230      -6.349 2.17e-10 ***
```

```
factor(year)1998 -0.266680   0.037390    -7.132 9.86e-13 ***
factor(year)1999 -0.321017   0.038095    -8.427  < 2e-16 ***
factor(year)2000 -0.364153   0.038200    -9.533  < 2e-16 ***
factor(year)2001 -0.255993   0.038488    -6.651 2.91e-11 ***
factor(year)2002 -0.494276   0.038723   -12.765  < 2e-16 ***
factor(year)2003 -0.482359   0.037962   -12.706  < 2e-16 ***
factor(year)2004 -0.524750   0.037496   -13.995  < 2e-16 ***
factor(year)2005 -0.509933   0.037264   -13.684  < 2e-16 ***
factor(year)2006 -0.439639   0.037369   -11.765  < 2e-16 ***
factor(year)2007 -0.472860   0.037888   -12.480  < 2e-16 ***
factor(year)2008 -0.573425   0.039367   -14.566  < 2e-16 ***
factor(year)2009 -0.270663   0.041020    -6.598 4.16e-11 ***
factor(year)2010 -0.457888   0.041261   -11.097  < 2e-16 ***
factor(year)2011 -0.620560   0.041396   -14.991  < 2e-16 ***
factor(year)2012 -0.481002   0.040916   -11.756  < 2e-16 ***
factor(year)2013 -0.574449   0.041250   -13.926  < 2e-16 ***
factor(year)2014 -0.349268   0.041349    -8.447  < 2e-16 ***
factor(year)2015 -0.234580   0.042070    -5.576 2.46e-08 ***
factor(year)2016 -0.346707   0.046164    -7.510 5.90e-14 ***
factor(qtr)1     -0.079795   0.006219   -12.831  < 2e-16 ***
factor(qtr)2     -0.089674   0.007070   -12.684  < 2e-16 ***
factor(qtr)3      0.060860   0.006499     9.364  < 2e-16 ***
factor(hpb2)1    -1.546421   0.008594 -179.947  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
             edf Ref.df Chi.sq p-value
s(lat,lon) 28.9   28.9  25151  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.259
glmer.ML = 6.6722e+05  Scale est. = 1         n = 350307
```

Summary of optimal model for area 2

glmm part

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) [glmerMod]

Family: poisson (log)

AIC	BIC	logLik	deviance	df.resid
570473.8	570810.5	-285205.9	570411.8	384878

Scaled residuals:

Min	1Q	Median	3Q	Max
-4.652	-0.541	-0.399	-0.243	107.340

Random effects:

Groups	Name	Variance	Std.Dev.
uid	(Intercept)	0.5975	0.773
Xr	s(lat,lon)	6.7042	2.589

Number of obs: 384909, groups: uid, 9404; Xr, 27

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
X(Intercept)	-7.013479	0.046526	-150.74	< 2e-16	***
Xfactor(year)1995	-0.041025	0.030038	-1.37	0.172014	
Xfactor(year)1996	0.152965	0.034648	4.41	1.01e-05	***
Xfactor(year)1997	-0.163233	0.037915	-4.31	1.67e-05	***
Xfactor(year)1998	-0.141701	0.037736	-3.76	0.000173	***
Xfactor(year)1999	0.169189	0.036620	4.62	3.84e-06	***
Xfactor(year)2000	0.293135	0.036847	7.96	1.78e-15	***
Xfactor(year)2001	0.361145	0.037598	9.61	< 2e-16	***
Xfactor(year)2002	0.197702	0.038350	5.16	2.53e-07	***
Xfactor(year)2003	0.167608	0.039798	4.21	2.54e-05	***
Xfactor(year)2004	0.055425	0.041101	1.35	0.177496	
Xfactor(year)2005	-0.060082	0.041890	-1.43	0.151496	
Xfactor(year)2006	0.131361	0.041545	3.16	0.001567	**
Xfactor(year)2007	0.087866	0.042750	2.06	0.039847	*
Xfactor(year)2008	0.319412	0.043216	7.39	1.46e-13	***

```
Xfactor(year)2009    0.301565      0.045276        6.66 2.73e-11 ***
Xfactor(year)2010    0.106173      0.046384        2.29 0.022081 *
Xfactor(year)2011    0.273601      0.048065        5.69 1.25e-08 ***
Xfactor(year)2012    0.278004      0.049711        5.59 2.24e-08 ***
Xfactor(year)2013    0.239513      0.052046        4.60 4.18e-06 ***
Xfactor(year)2014    0.137022      0.055551        2.47 0.013641 *
Xfactor(year)2015    0.287656      0.062181        4.63 3.73e-06 ***
Xfactor(year)2016    0.287263      0.071925        3.99 6.50e-05 ***
Xfactor(qtr)1        0.138912      0.009610       14.46    < 2e-16 ***
Xfactor(qtr)2       -0.103427      0.011439       -9.04    < 2e-16 ***
Xfactor(qtr)3       -0.171304      0.009877      -17.34    < 2e-16 ***
Xfactor(hpb2)1      -2.424871      0.037249      -65.10    < 2e-16 ***
Xs(lat,lon)Fx1       0.797157      0.032625       24.43    < 2e-16 ***
Xs(lat,lon)Fx2       0.074862      0.026064        2.87 0.004076 **
---
Signif. codes:    0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation matrix not shown by default, as p = 29 > 12.
Use print(x, correlation=TRUE)    or
                 vcov(x)    if you need it
```

gam part

```
Family: poisson
Link function: log

Formula:
swo ~ factor(year) + factor(qtr) + s(lat, lon) + factor(hpb2) +
       offset(log(hooks))

Parametric coefficients:
                          Estimate Std. Error    z value Pr(>|z|)
(Intercept)          -7.013479      0.047314 -148.233    < 2e-16 ***
factor(year)1995 -0.041025      0.030576      -1.342 0.179684
factor(year)1996    0.152965      0.035276       4.336 1.45e-05 ***
factor(year)1997 -0.163233      0.038698      -4.218 2.46e-05 ***
factor(year)1998 -0.141701      0.038530      -3.678 0.000235 ***
factor(year)1999    0.169189      0.037380       4.526 6.00e-06 ***
```

factor(year)2000	0.293135	0.037627	7.791	6.67e-15	***
factor(year)2001	0.361145	0.038363	9.414	< 2e-16	***
factor(year)2002	0.197702	0.039194	5.044	4.55e-07	***
factor(year)2003	0.167608	0.040601	4.128	3.66e-05	***
factor(year)2004	0.055425	0.041957	1.321	0.186496	
factor(year)2005	-0.060082	0.042756	-1.405	0.159952	
factor(year)2006	0.131361	0.042443	3.095	0.001968	**
factor(year)2007	0.087866	0.043684	2.011	0.044285	*
factor(year)2008	0.319412	0.044151	7.235	4.67e-13	***
factor(year)2009	0.301565	0.046150	6.534	6.39e-11	***
factor(year)2010	0.106173	0.047287	2.245	0.024749	*
factor(year)2011	0.273601	0.049075	5.575	2.47e-08	***
factor(year)2012	0.278004	0.050717	5.481	4.22e-08	***
factor(year)2013	0.239513	0.053342	4.490	7.12e-06	***
factor(year)2014	0.137022	0.056807	2.412	0.015863	*
factor(year)2015	0.287656	0.063298	4.544	5.51e-06	***
factor(year)2016	0.287263	0.073515	3.908	9.32e-05	***
factor(qtr)1	0.138912	0.009656	14.386	< 2e-16	***
factor(qtr)2	-0.103427	0.011484	-9.006	< 2e-16	***
factor(qtr)3	-0.171304	0.009946	-17.223	< 2e-16	***
factor(hpb2)1	-2.424871	0.037455	-64.740	< 2e-16	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value	
s(lat,lon)	28.88	28.88	10214	<2e-16	***

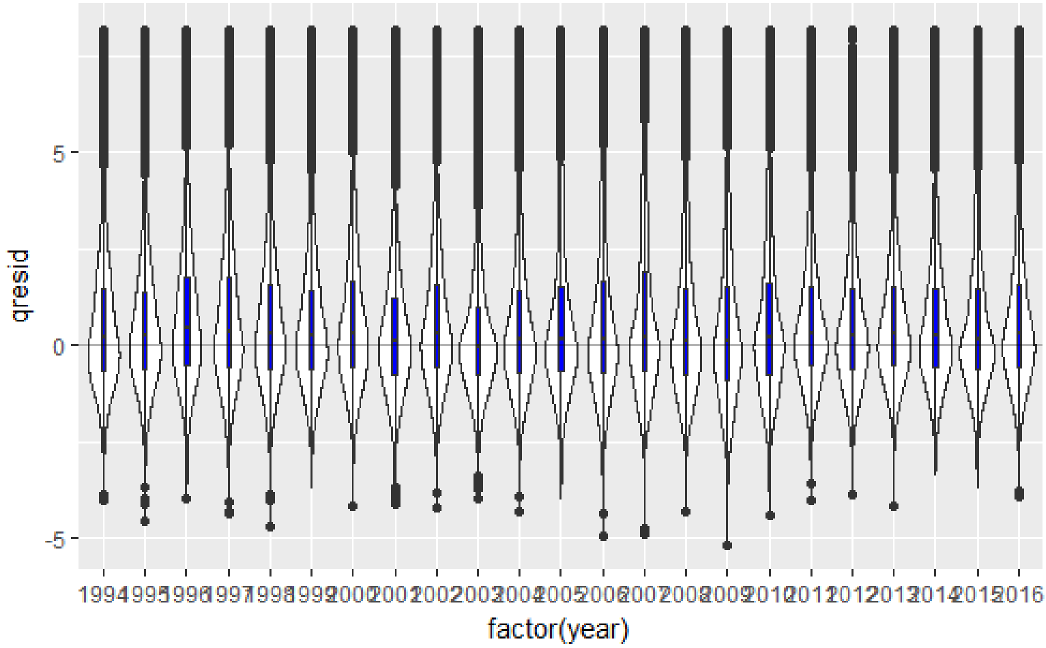
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

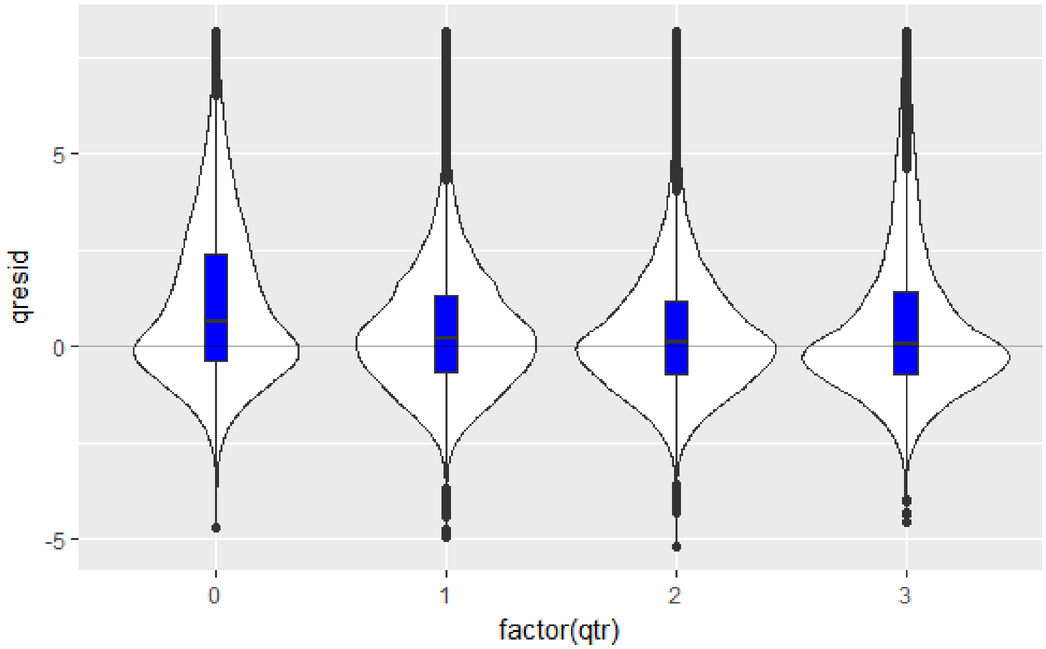
R-sq.(adj) = 0.371

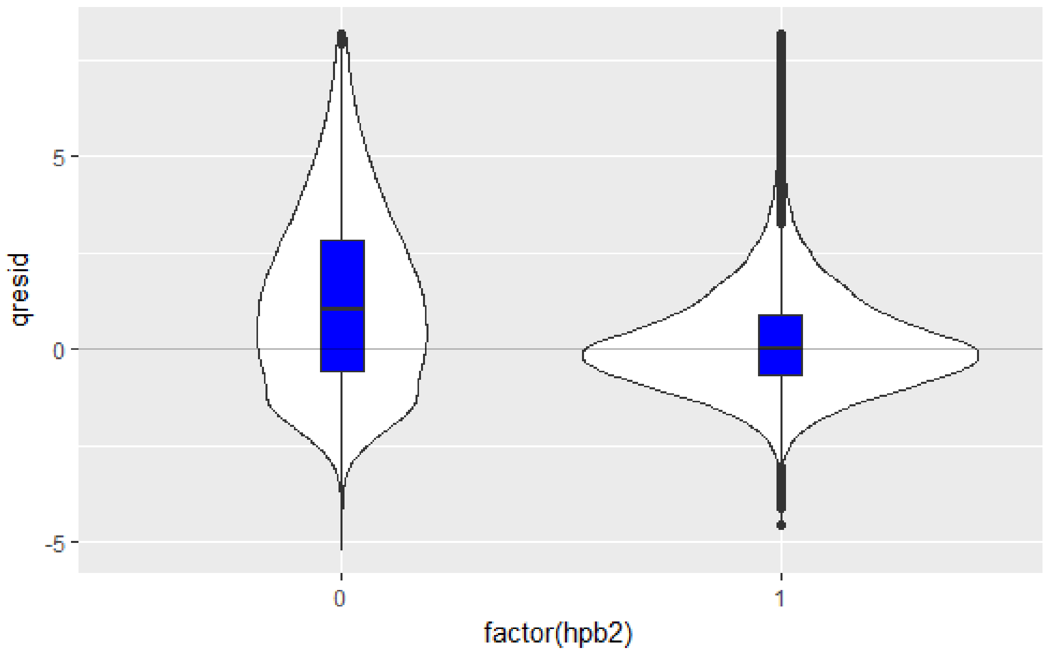
glmer.ML = 3.4701e+05 Scale est. = 1 n = 384909

Randomized quantile residuals pattern for each categorical factors and each area

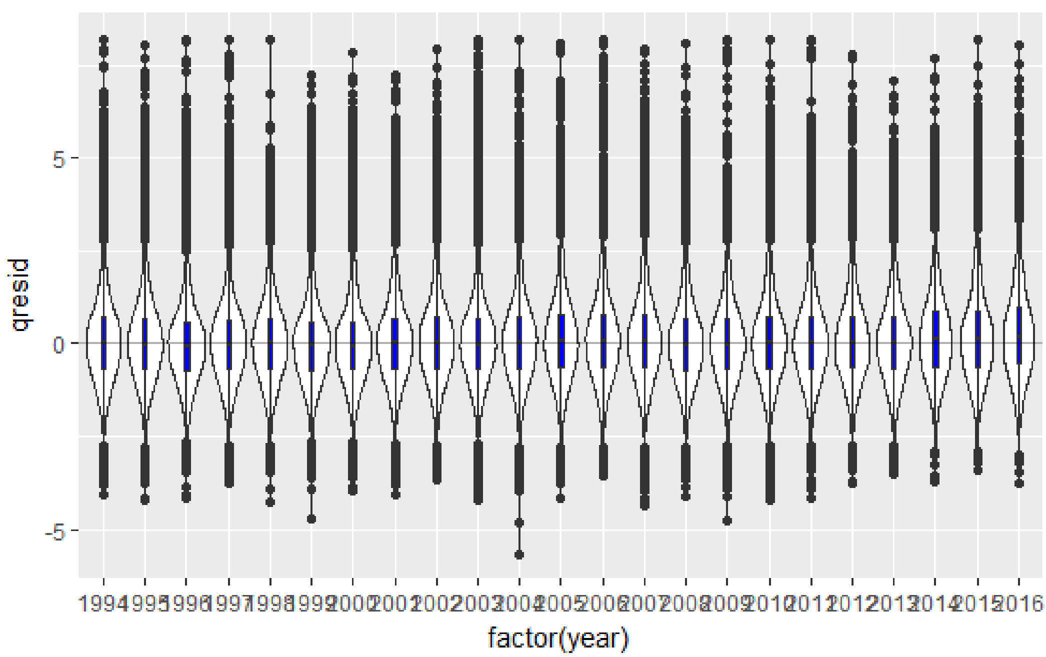
area 1

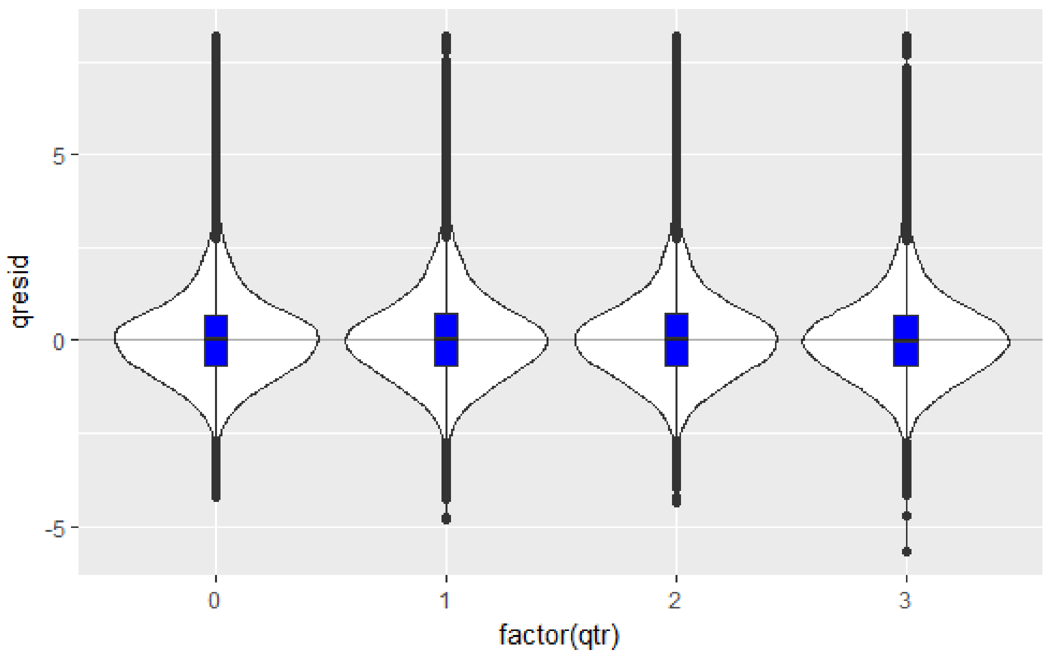


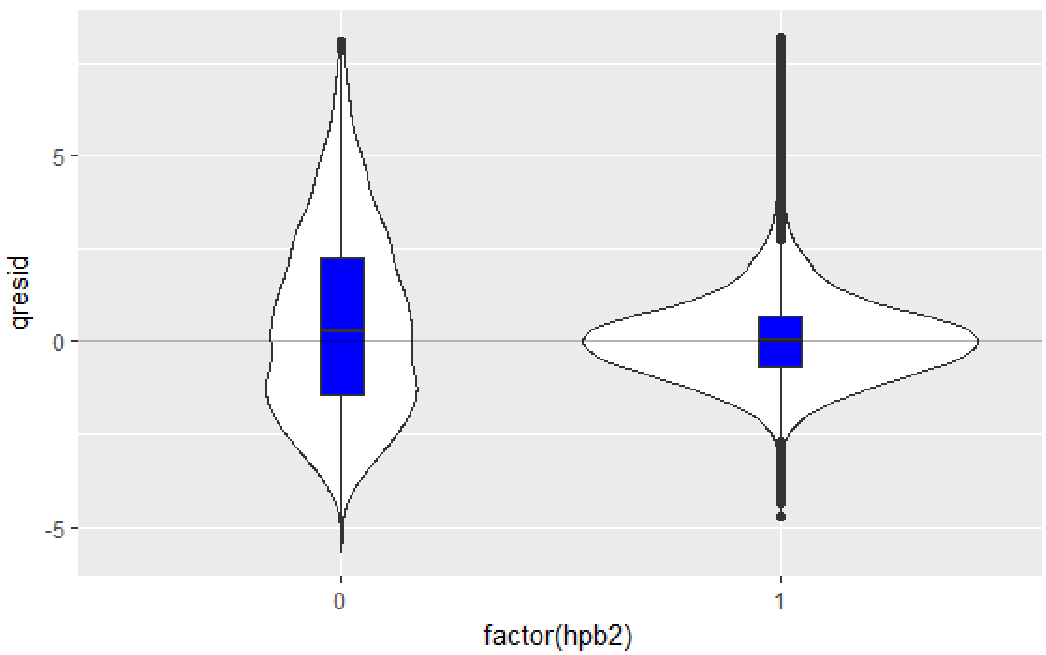




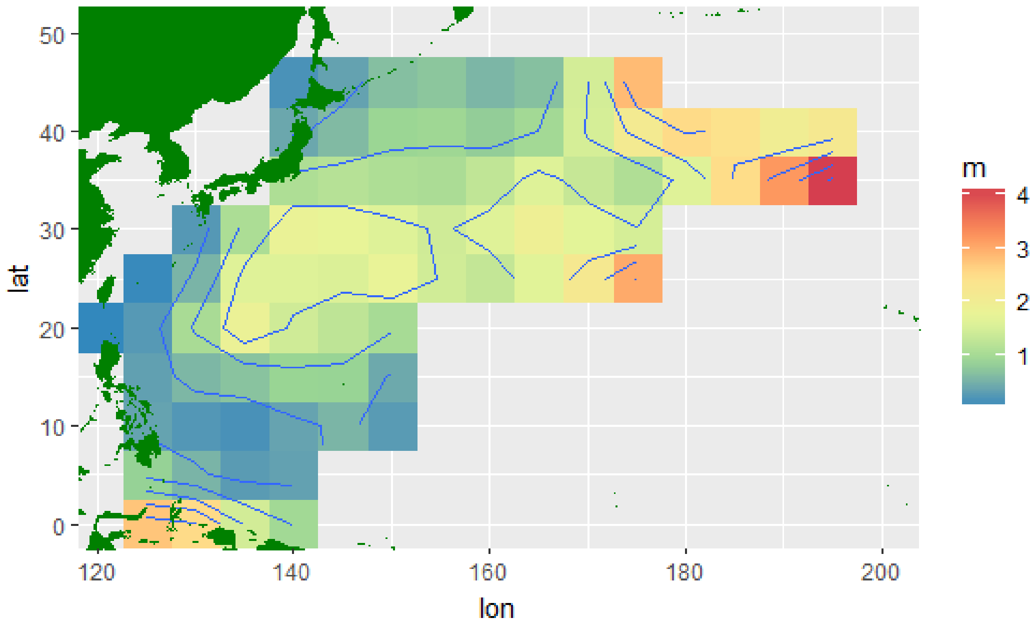
area 2

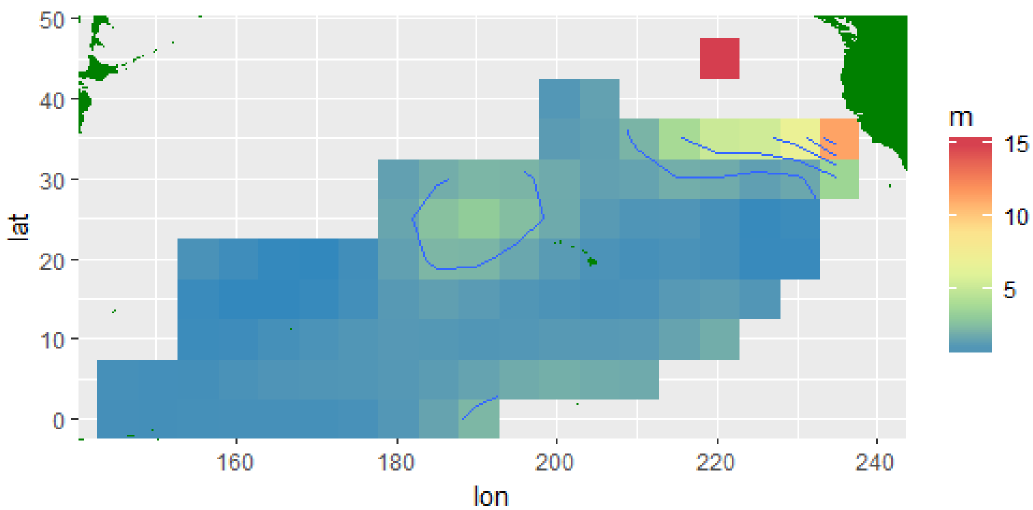



qresid
5
0
-5
0
1
2
3
factor(qtr)


qresid
5
0
-5
0
1
factor(hpb2)

Estimated spatial distribution of standardized CPUE for each area





Appendix 2

Standardization without deep set by gamm

	sCPUE	SE
1994	1.686879	0.031021
1995	1.699239	0.027563
1996	1.436119	0.027024
1997	1.440245	0.028236
1998	1.401259	0.029089
1999	1.421794	0.02965
2000	1.355468	0.028858
2001	1.59368	0.029352
2002	1.220076	0.029983
2003	1.304315	0.029767
2004	1.253722	0.028962
2005	1.330638	0.028517
2006	1.397026	0.028305
2007	1.330171	0.028722
2008	1.096158	0.031394
2009	1.421947	0.033776
2010	1.228973	0.035292
2011	1.140424	0.037208
2012	1.352029	0.036918
2013	1.331025	0.036815
2014	1.661746	0.03673
2015	1.948601	0.038025
2016	1.489198	0.044245

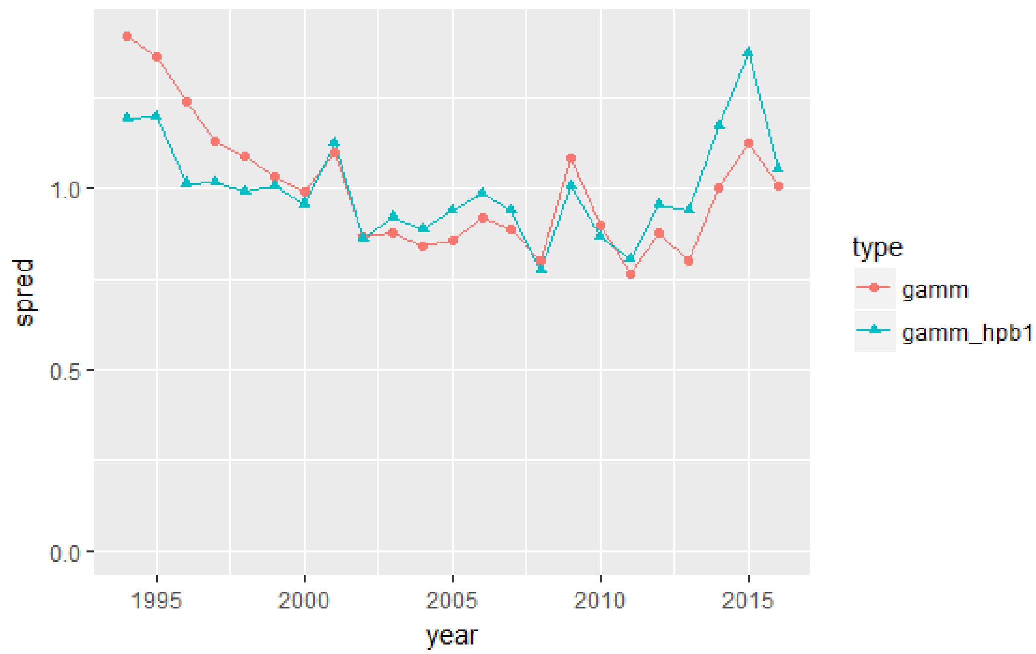


Fig A2-1

Comparison of annual trend of sCPUE by gamm with alldata set and without deep set.

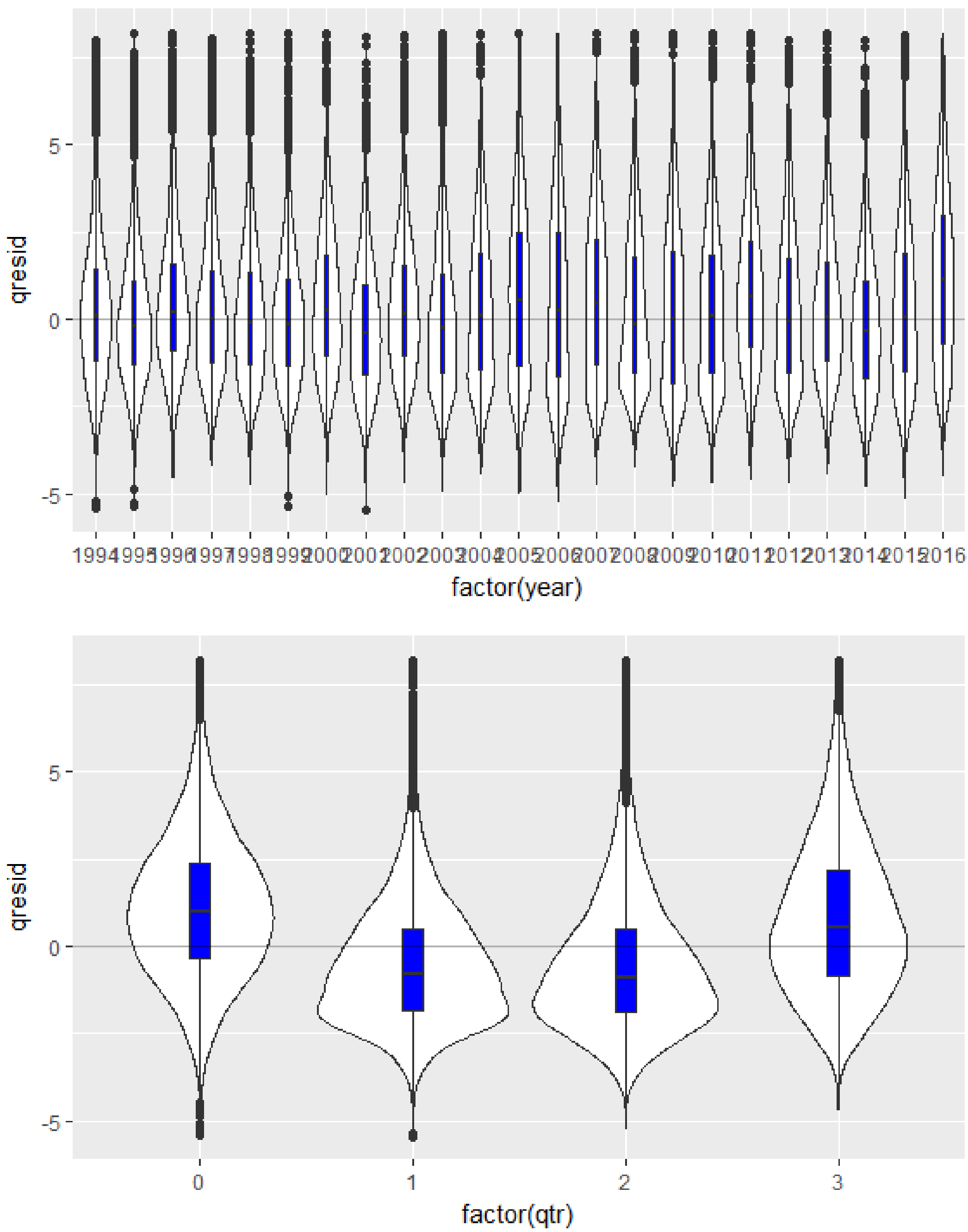


Fig A2-2

The distribution of randomized quantile residuals for each factors.

Appendix 3 standardized CPUE between 1975 and 1993

Materials and Methods

In this study, set by set data including year, season and gear configurations between 1975 and 1993 were used for the analysis. The operation area was separated by the same definition with Ichinokawa and Brodziak (2010) and Ijima and Kanaiwa (2018) (Fig. 1). In this analysis, we focused only area 1 and 2, i.e. in the North-Western Central Pacific. The gear configurations was separated to 0) 3-5 and 1) >6 HPB. Data of sets with its HPB is smaller than 2 or larger than 23 were excluded from the analysis. All data number for each area was shown in Table 1.

The standardized model was conducted as the following equation.

number of caught sword fish~ year + quarter + gear + lat + lon + offset(log(hooks)) + poisson error. As the model, we used generalized linear model with Poisson distribution (glm) and glm with negative binomial distribution (glmnb). We addressed some mixture model and additive model but they were not converged. The optimal model was selected by BIC.

Result and discussion

The glms with negative binomial distribution were selected for both area as optimal models (Table A3-2). The total explanatory deviances were 29.2% and 3.5% for area 1 and 2, respectively (Table A3-3). The pattern of randomized quantile residuals were not found any skew and median was close to 0 for each category (Fig. A3-1). There were some issue in the explanatory deviances but no issues on the distribution of randomized quantile residuals. Therefore more explanatory variables or reconsideration of the statistical model was required in future. However we concluded these were best available indices from early Japanese longline in the North West Pacific Ocean in this moment. The comparison of CPUEs were shown in Fig. A3-2 and all standardized CPUE had flatter trend than the one of nominal CPUE. The annual trend and standard deviation of standardized CPUE by optimal model were provided in TableA3-4 and Fig. A3-3. The Pearson product-moment correlation coefficient between nominal and standardized CPUEs were provided on Table A3-5. In the area 2 had larger values rather than area1.

Table A3-1 The number of data for each category and total

Area 1

	season				gear		
year	0	1	2	3	shallow	deep	total
1975	7,810	6,022	5,449	9,765	21,742	7,304	29,046
1976	14,456	7,875	9,254	16,165	32,456	15,294	47,750
1977	15,702	11,199	8,476	14,640	28,960	21,057	50,017
1978	14,869	10,906	10,084	18,360	29,889	24,330	54,219
1979	15,472	12,689	10,575	14,078	26,171	26,643	52,814
1980	11,744	9,344	5,381	17,538	21,972	22,035	44,007
1981	20,410	12,035	9,247	17,747	27,190	32,249	59,439
1982	16,331	8,471	7,654	13,671	17,411	28,716	46,127
1983	14,728	8,501	5,807	15,255	15,906	28,385	44,291
1984	17,368	5,721	7,900	17,209	14,101	34,097	48,198
1985	14,184	7,938	7,707	14,465	13,224	31,070	44,294
1986	12,843	7,856	6,721	12,984	12,541	27,863	40,404
1987	10,140	7,680	5,580	13,096	12,698	23,798	36,496
1988	10,407	8,370	6,560	13,714	10,887	28,164	39,051
1989	11,806	8,673	7,291	14,616	9,985	32,401	42,386
1990	12,700	9,826	4,891	11,616	8,687	30,346	39,033
1991	10,965	9,841	5,998	12,379	7,798	31,385	39,183
1992	10,549	4,963	4,550	11,236	8,202	23,096	31,298
1993	10,505	8,673	4,913	12,331	8,291	28,131	36,422

Area 2

	season				gear		
year	0	1	2	3	shallow	deep	total
1975	7,841	3,697	3,843	2,496	11,448	6,429	17,877
1976	6,633	9,177	6,562	3,602	13,483	12,491	25,974
1977	8,036	6,603	5,508	3,531	9,687	13,991	23,678
1978	6,955	7,522	4,979	3,748	7,292	15,912	23,204
1979	9,169	8,877	6,709	5,221	9,933	20,043	29,976
1980	13,665	9,069	6,677	3,867	11,725	21,553	33,278
1981	10,330	10,723	9,772	4,684	9,515	25,994	35,509
1982	12,569	12,010	6,183	5,539	6,177	30,124	36,301
1983	11,153	9,482	4,519	3,039	2,679	25,514	28,193
1984	11,467	11,180	8,399	4,462	1,812	33,696	35,508
1985	13,039	9,562	5,530	2,543	905	29,769	30,674
1986	9,699	8,068	5,560	4,087	517	26,897	27,414
1987	10,729	8,936	6,118	4,092	265	29,610	29,875
1988	10,235	6,863	4,388	3,773	331	24,928	25,259
1989	9,324	7,795	4,830	3,269	430	24,788	25,218
1990	10,058	6,391	5,251	3,371	219	24,852	25,071
1991	7,849	6,340	4,639	2,484	52	21,260	21,312
1992	6,685	6,516	4,290	2,238	57	19,672	19,729
1993	8,421	5,958	4,429	2,474	28	21,254	21,282

Table A3-2 BIC of each model

	area1	area2
glm	4,165,203	850,646
glm.nb	2,763,274	718,736

Table A3-3 residuals deviances

Area 1

	Df	Deviance	Resid. Df	Resid. Dev	% Deviance	Pr(>Chi)
NULL			824474	1022503		
year	18	10274	824456	1012229	1.00	< 2.2e-16
quarter	3	28861	824453	983368	2.85	< 2.2e-16
lat	1	152723	824452	830645	15.53	< 2.2e-16
lon	1	6816	824451	823829	0.82	< 2.2e-16
hpb	1	74387	824450	749442	9.03	< 2.2e-16

Area 2

	Df	Deviance	Resid. Df	Resid. Dev	% Deviance	Pr(>Chi)
NULL			515331	305341		
year	18	2725.8	515313	302616	0.89	< 2.2e-16
quarter	3	3719.3	515310	298896	1.23	< 2.2e-16
lat	1	2679.7	515309	296217	0.90	< 2.2e-16
lon	1	1275.1	515308	294942	0.43	< 2.2e-16
hpb	1	74	515307	294868	0.03	< 2.2e-16

Table A3-4 nominal and standardized CPUE for each area

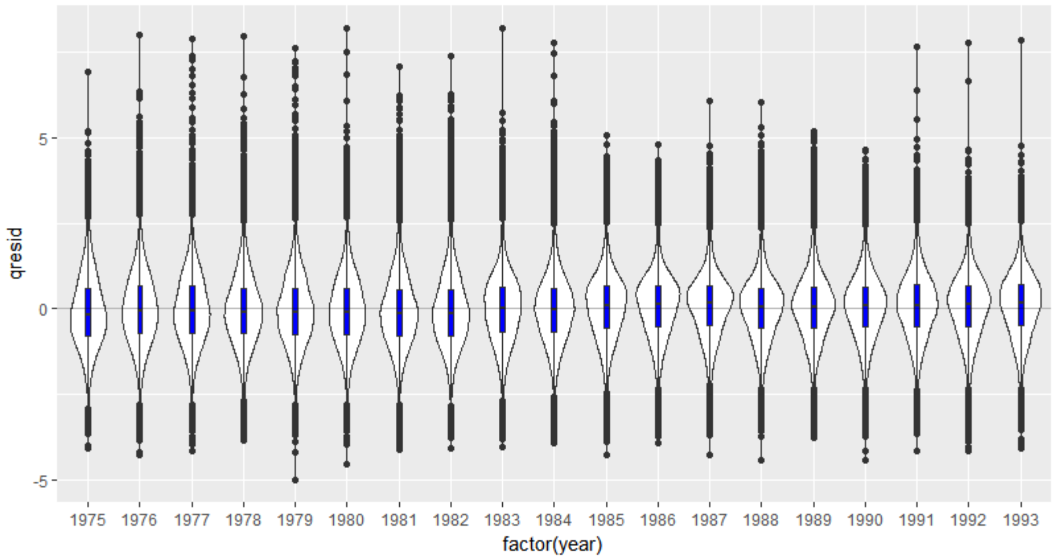
	area1			area 2		
year	nCPUE	sCPUE	SE	nCPUE	sCPUE	SE
1975	1.10407	1.82075	0.01003	0.17159	0.12809	0.01919
1976	0.98913	1.76569	0.00803	0.19558	0.13893	0.01641
1977	1.01967	1.69975	0.00805	0.21344	0.16794	0.01691
1978	0.85559	1.44877	0.00808	0.17089	0.13037	0.01828
1979	0.91041	1.58266	0.00811	0.13655	0.11224	0.01716
1980	0.91385	1.46391	0.00883	0.15538	0.13667	0.01576
1981	0.88254	1.45460	0.00772	0.16979	0.13678	0.01602
1982	0.89388	1.44274	0.00861	0.11896	0.10145	0.01701
1983	1.17351	1.70831	0.00865	0.11473	0.09730	0.01894
1984	1.07708	1.68399	0.00843	0.13257	0.11429	0.01723
1985	1.41303	2.13450	0.00860	0.15586	0.13835	0.01741
1986	1.26165	1.90171	0.00889	0.15994	0.13631	0.01809
1987	1.35509	2.03575	0.00916	0.14213	0.12393	0.01787
1988	1.11369	1.73089	0.00917	0.13086	0.10743	0.01902
1989	0.87875	1.60126	0.00909	0.12780	0.10246	0.01915
1990	0.91124	1.74923	0.00939	0.12079	0.10660	0.01932
1991	0.73575	1.56808	0.00958	0.11869	0.09701	0.02062
1992	0.85729	1.39716	0.01026	0.10593	0.09095	0.02161
1993	0.86675	1.46994	0.00986	0.13338	0.11286	0.01999

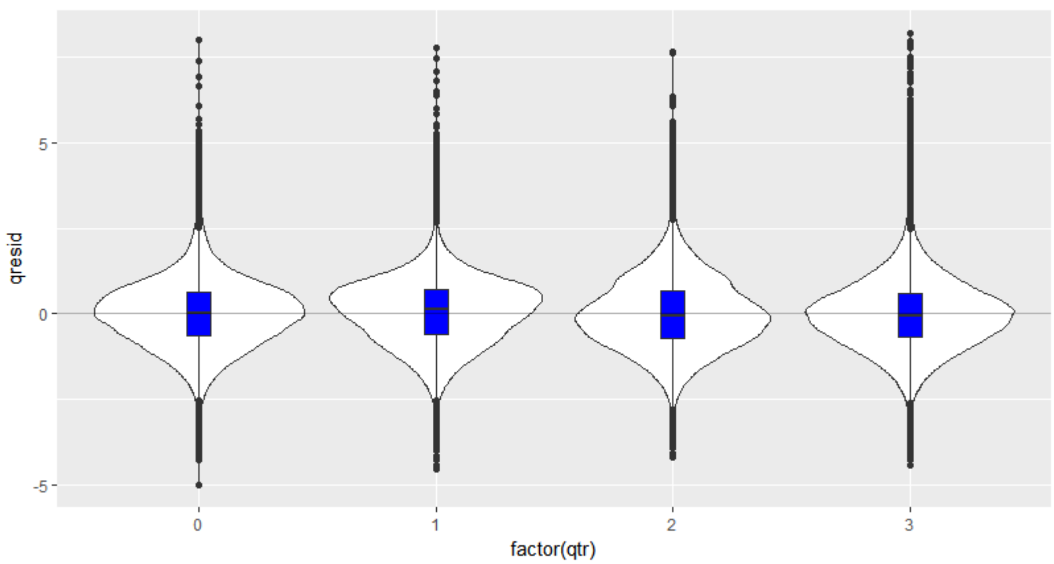
Table A3-5 The Pearson product-moment correlation coefficient between nominal and standardized CPUEs

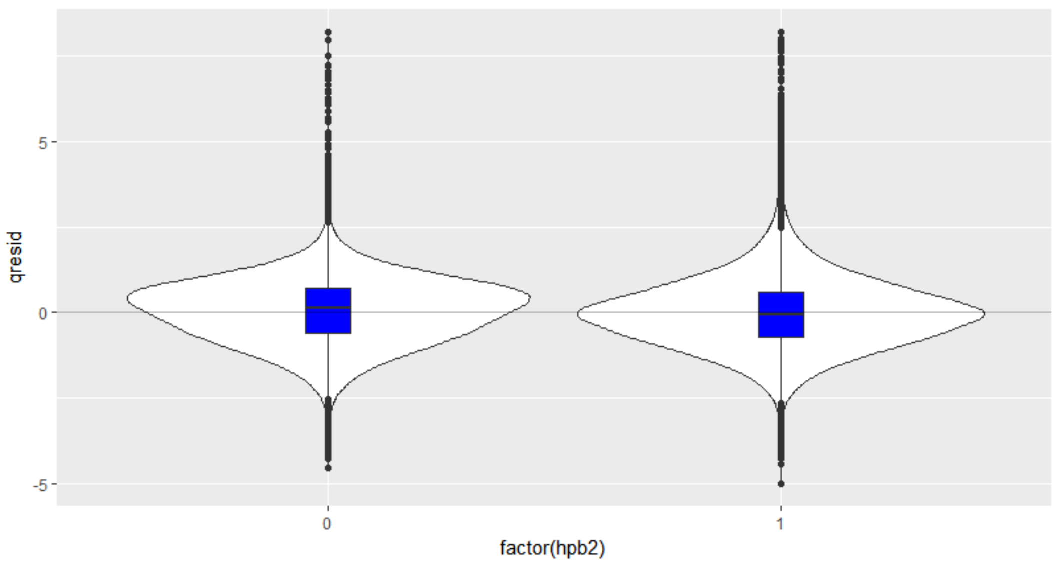
area 1	area 2
0.890	0.945

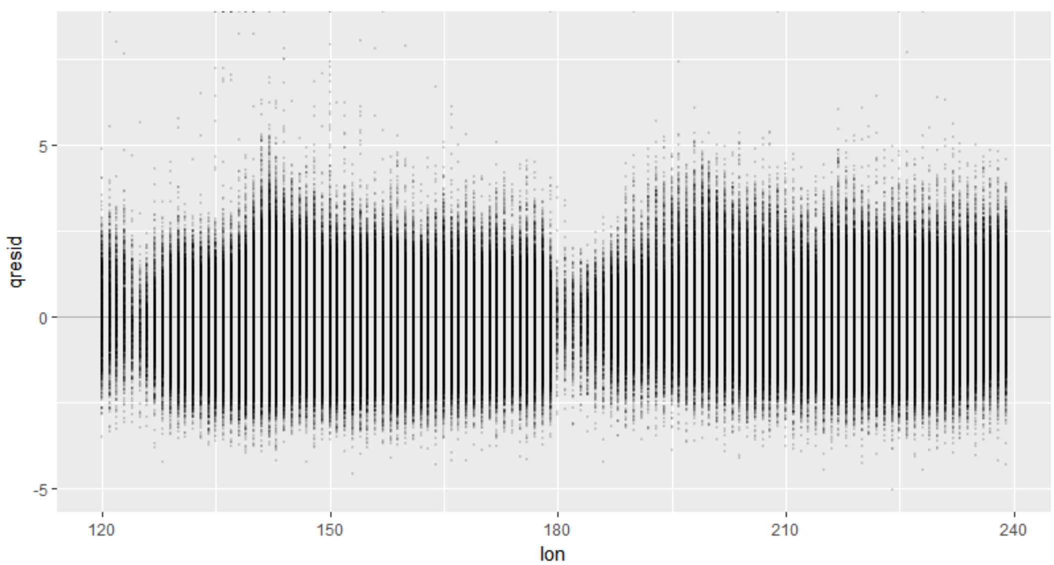
Fig A3-1 quantile residuals

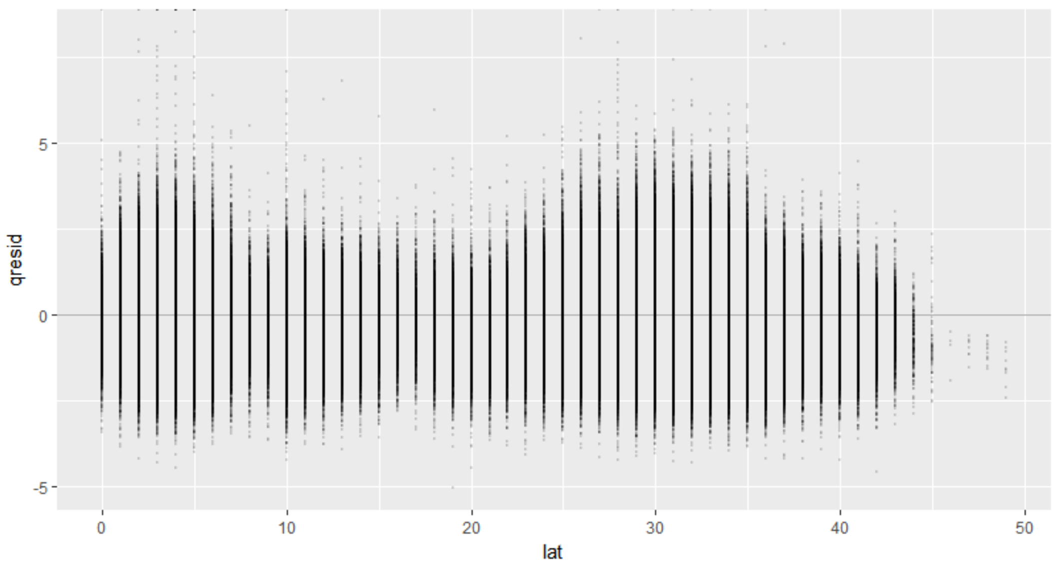
area 1



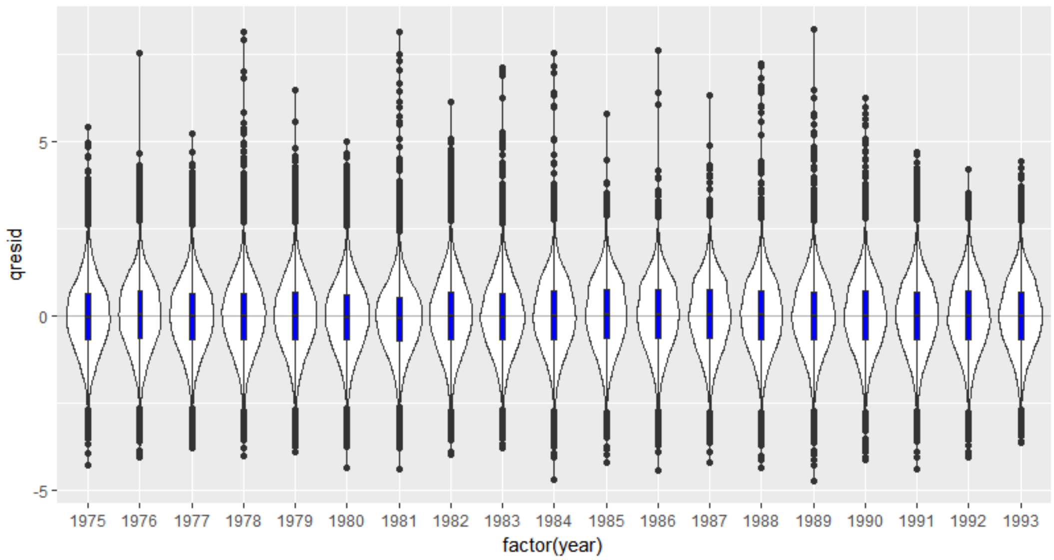


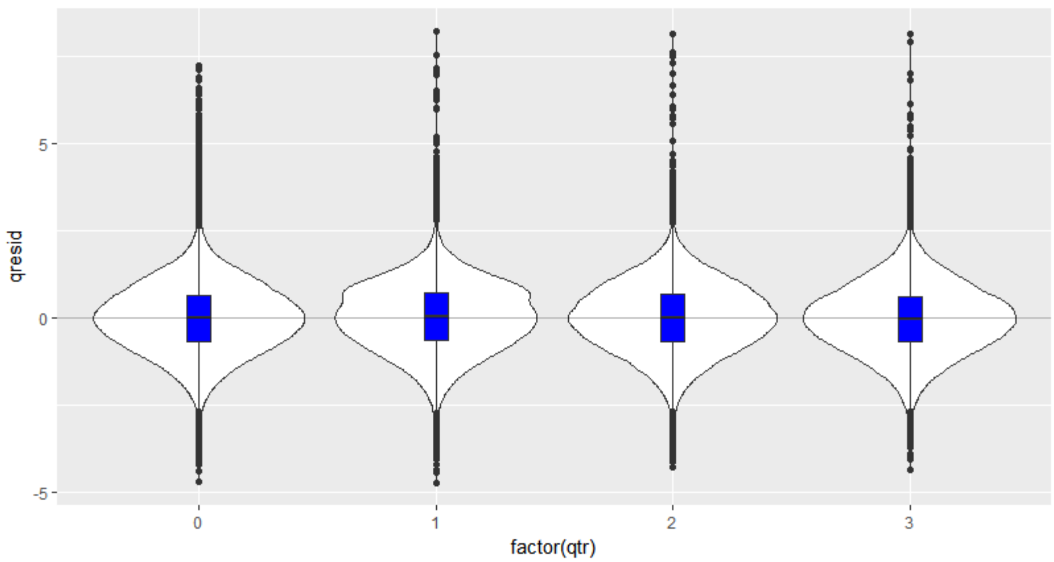

qresid
5
0
-5
0
1
factor(hpb2)

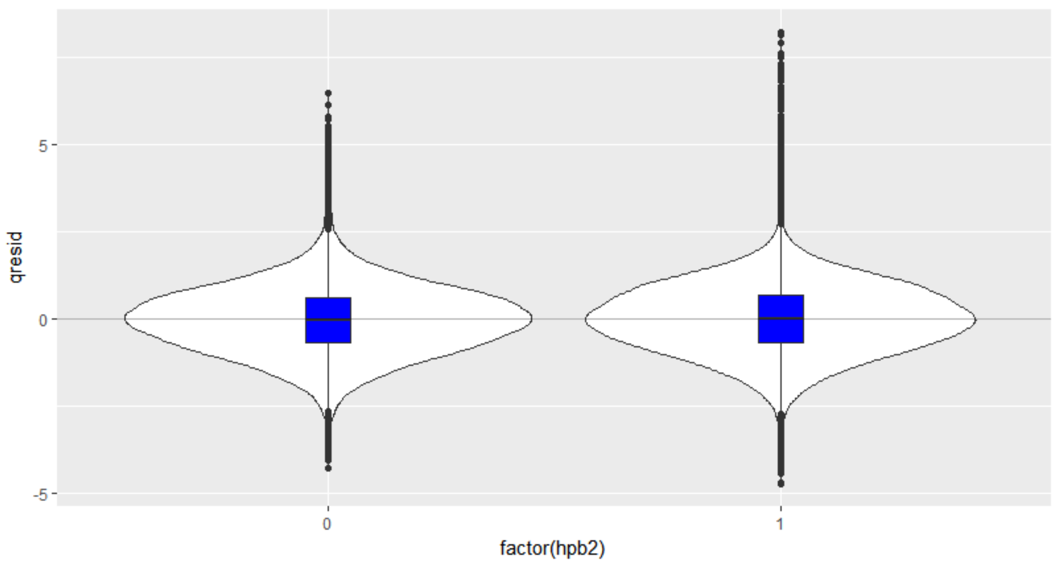

qresid
5
0
-5
120
150
180
210
240
lon

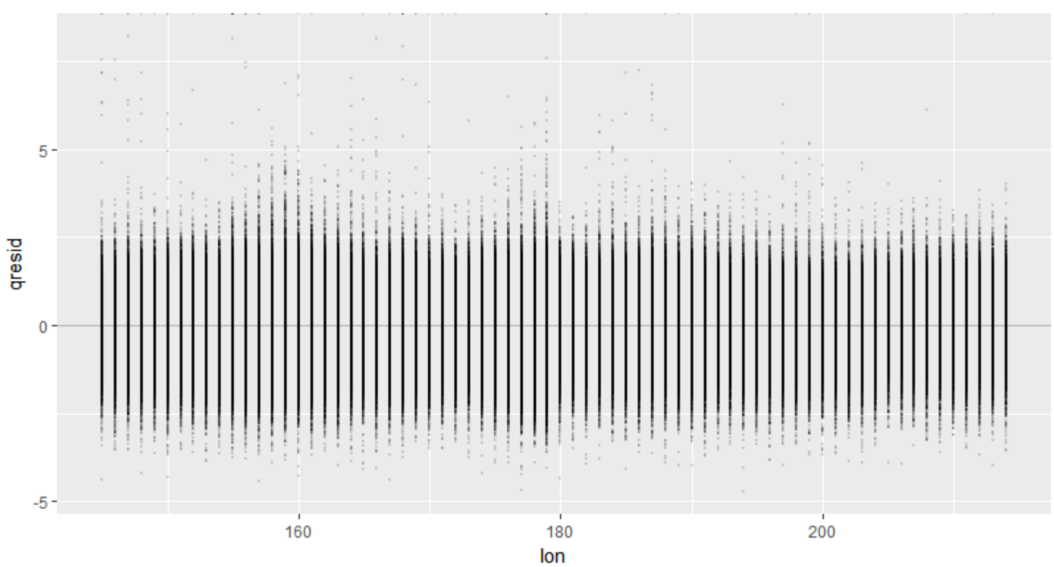

qresid
lat
5
0
-5
0
10
20
30
40
50

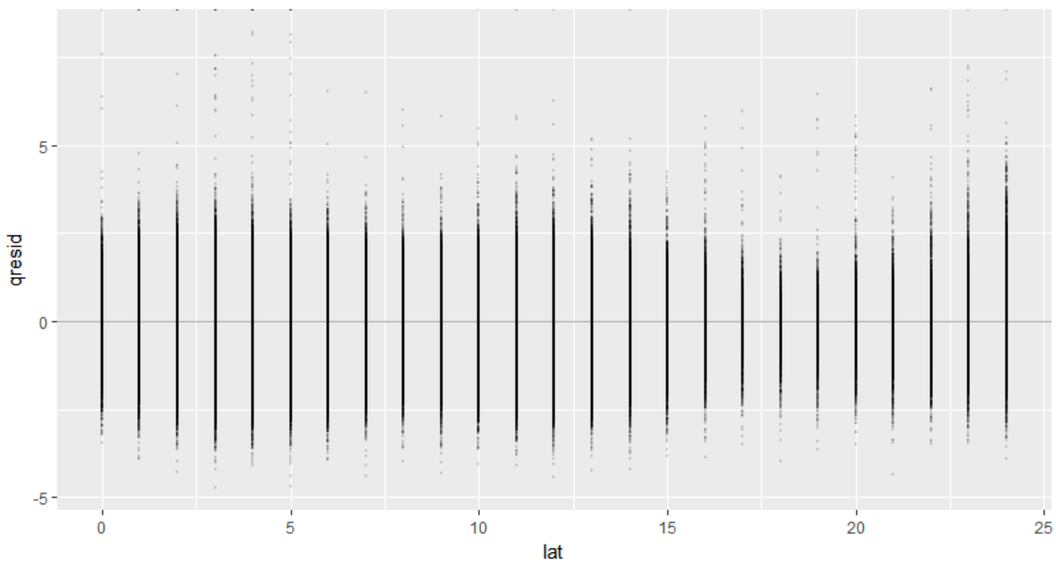
area 2


qresid
5
0
-5
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
factor(year)


qresid
5
0
-5
0
1
2
3
factor(qtr)


5
0
-5
qresid
0
1
factor(hpb2)

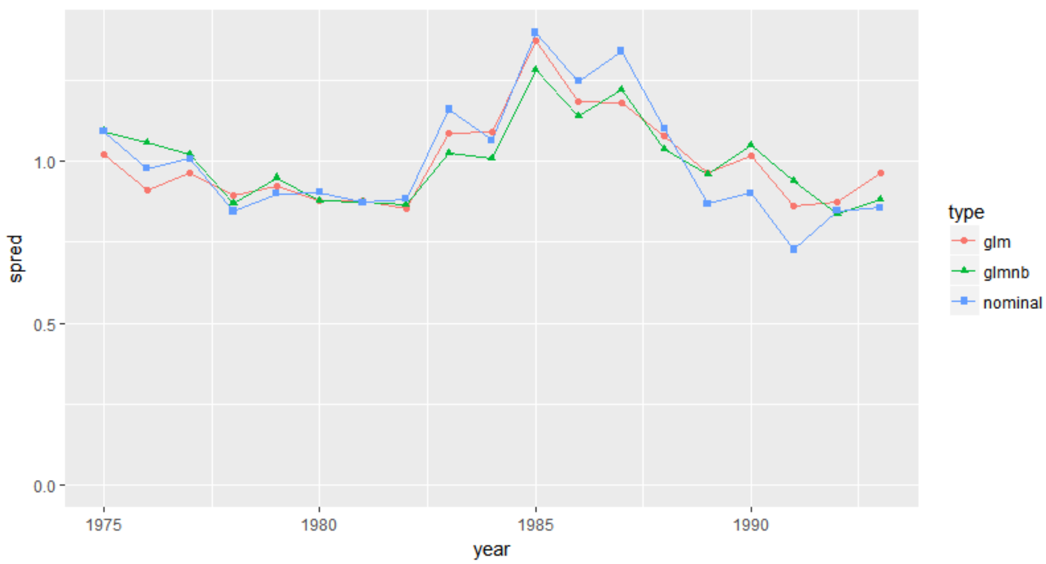

5
0
-5
qresid
160
180
200
lon



qresid
5
0
-5
0
5
10
15
20
25
lat

Fig. A3-2 Comparison of CPUEs

area 1



area 2

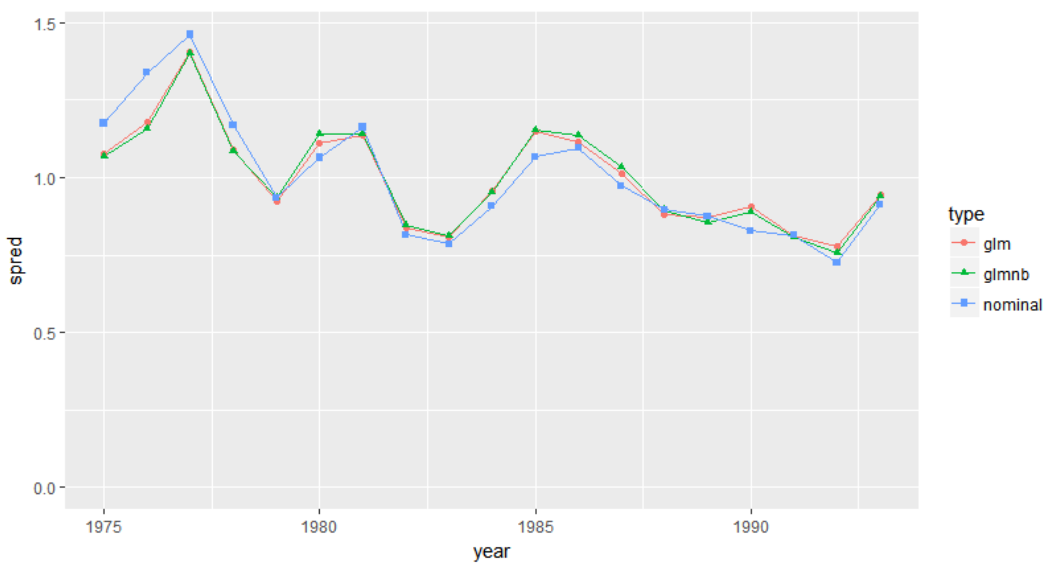
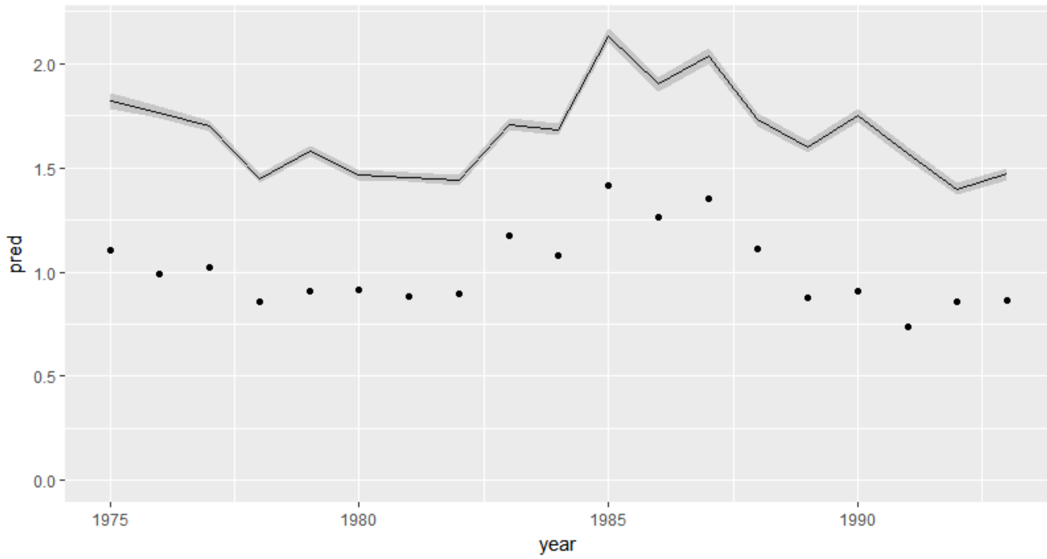
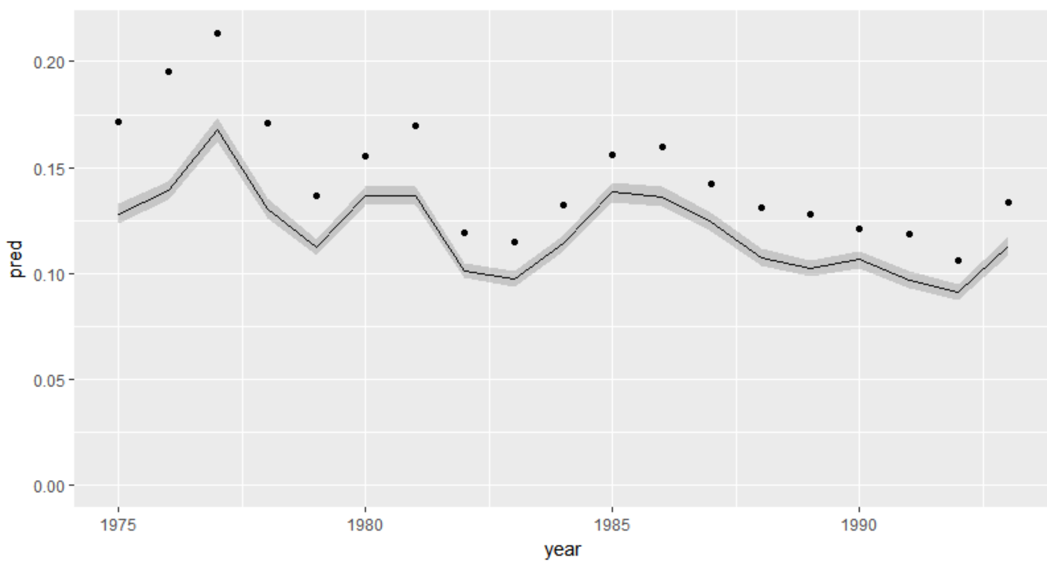


Fig. A3-3

Area 1



Area 2



Output of summary

Area 1

```
Call:
glm.nb(formula = swo ~ factor(year) + factor(qtr) + lat + lon +
    factor(hpb2) + offset(log(hooks)), data = adata0, init.theta = 0.5205518203,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.021   -1.058   -0.699    0.152   44.289

Coefficients:
                     Estimate Std. Error  z value Pr(>|z|)
(Intercept)        -7.992e+00  1.574e-02 -507.809  < 2e-16 ***
factor(year)1976 -3.071e-02  1.217e-02   -2.524 0.011606 *
factor(year)1977 -6.877e-02  1.214e-02   -5.663 1.49e-08 ***
factor(year)1978 -2.285e-01  1.215e-02  -18.812  < 2e-16 ***
factor(year)1979 -1.401e-01  1.218e-02  -11.503  < 2e-16 ***
factor(year)1980 -2.181e-01  1.263e-02  -17.277  < 2e-16 ***
factor(year)1981 -2.245e-01  1.194e-02  -18.808  < 2e-16 ***
factor(year)1982 -2.327e-01  1.253e-02  -18.574  < 2e-16 ***
factor(year)1983 -6.375e-02  1.252e-02   -5.090 3.57e-07 ***
factor(year)1984 -7.809e-02  1.238e-02   -6.306 2.87e-10 ***
factor(year)1985  1.590e-01  1.246e-02   12.759  < 2e-16 ***
factor(year)1986  4.350e-02  1.267e-02    3.434 0.000594 ***
factor(year)1987  1.116e-01  1.285e-02    8.685  < 2e-16 ***
factor(year)1988 -5.062e-02  1.285e-02   -3.939 8.18e-05 ***
factor(year)1989 -1.285e-01  1.283e-02  -10.016  < 2e-16 ***
factor(year)1990 -4.007e-02  1.306e-02   -3.069 0.002145 **
factor(year)1991 -1.494e-01  1.314e-02  -11.372  < 2e-16 ***
factor(year)1992 -2.648e-01  1.370e-02  -19.327  < 2e-16 ***
factor(year)1993 -2.140e-01  1.334e-02  -16.046  < 2e-16 ***
factor(qtr)1       -2.824e-02  5.520e-03   -5.117 3.11e-07 ***
factor(qtr)2       -6.134e-01  5.848e-03 -104.891  < 2e-16 ***
factor(qtr)3       -6.676e-01  4.624e-03 -144.385  < 2e-16 ***
lat                 5.693e-02  1.946e-04  292.497  < 2e-16 ***
```

```
lon                  2.175e-03   6.514e-05     33.395   < 2e-16 ***
factor(hpb2)1     -1.167e+00   4.257e-03 -274.095   < 2e-16 ***
---
Signif. codes:   0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(0.5206) family taken to be 1)

    Null deviance: 1022503   on 824474   degrees of freedom
Residual deviance:   749442   on 824450   degrees of freedom
AIC: 2762971

Number of Fisher Scoring iterations: 1


              Theta:   0.52055
          Std. Err.:   0.00142

 2 x log-likelihood:   -2762919.40100
```

Area 2

Call:

```
glm.nb(formula = swo ~ factor(year) + factor(qtr) + lat + lon +
    factor(hpb2) + offset(log(hooks)), data = adata1, init.theta = 0.3803036786,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.414   -0.695   -0.623   -0.533   39.967

Coefficients:
                   Estimate Std. Error   z value Pr(>|z|)
(Intercept)       -1.041e+01  3.826e-02 -272.096  < 2e-16 ***
factor(year)1976   8.122e-02  2.338e-02    3.473 0.000514 ***
factor(year)1977   2.709e-01  2.365e-02   11.452  < 2e-16 ***
factor(year)1978   1.765e-02  2.442e-02    0.723 0.469666
factor(year)1979  -1.321e-01  2.368e-02   -5.578 2.43e-08 ***
factor(year)1980   6.481e-02  2.291e-02    2.829 0.004673 **
factor(year)1981   6.564e-02  2.266e-02    2.897 0.003772 **
factor(year)1982  -2.332e-01  2.343e-02   -9.951  < 2e-16 ***
factor(year)1983  -2.750e-01  2.479e-02  -11.094  < 2e-16 ***
factor(year)1984  -1.140e-01  2.342e-02   -4.868 1.13e-06 ***
factor(year)1985   7.707e-02  2.368e-02    3.254 0.001139 **
factor(year)1986   6.221e-02  2.395e-02    2.598 0.009389 **
factor(year)1987  -3.300e-02  2.382e-02   -1.386 0.165858
factor(year)1988  -1.759e-01  2.466e-02   -7.136 9.64e-13 ***
factor(year)1989  -2.233e-01  2.479e-02   -9.008  < 2e-16 ***
factor(year)1990  -1.836e-01  2.502e-02   -7.338 2.16e-13 ***
factor(year)1991  -2.780e-01  2.588e-02  -10.743  < 2e-16 ***
factor(year)1992  -3.424e-01  2.675e-02  -12.801  < 2e-16 ***
factor(year)1993  -1.266e-01  2.548e-02   -4.968 6.75e-07 ***
factor(qtr)1       5.007e-01  8.431e-03   59.393  < 2e-16 ***
factor(qtr)2       2.558e-01  1.004e-02   25.472  < 2e-16 ***
factor(qtr)3       7.911e-02  1.163e-02    6.801 1.04e-11 ***
lat                3.135e-02  6.554e-04   47.838  < 2e-16 ***
lon                6.847e-03  1.895e-04   36.128  < 2e-16 ***
```

```
factor(hpb2)1       -8.966e-02   1.061e-02     -8.448    < 2e-16 ***
---
Signif. codes:   0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(0.3803) family taken to be 1)

    Null deviance: 305341   on 515331   degrees of freedom
Residual deviance: 294868   on 515307   degrees of freedom
AIC: 718446

Number of Fisher Scoring iterations: 1


              Theta:   0.38030
          Std. Err.:   0.00257

 2 x log-likelihood:   -718394.43900
```