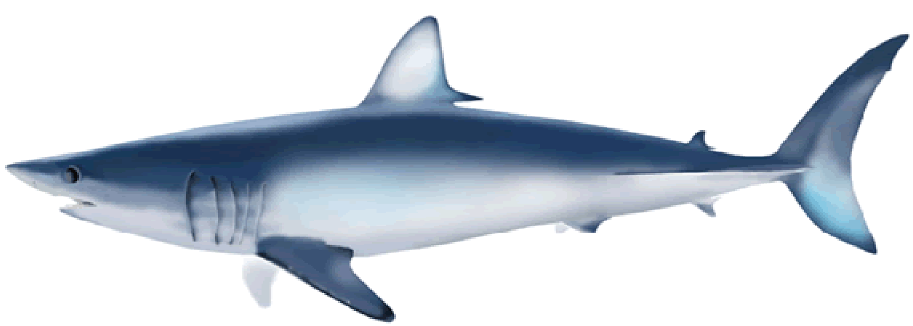
Extraction of blue shark catches from species-combined catches of sharks in the log-book data of Japanese offshore and distant-water longliners operated in the North Pacific in the period between 1975 and 1993

Yuko Hiraoka, Minoru Kanaiwa and Kotaro Yokawa

National Research Institute of Far Seas Fisheries, Fishery Research Agency
5-7-1 Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN
Email: yhira415@affrc.go.jp



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Abstract

The extraction method of blue shark only catch is developped becuse the log-book data of Japanese longliners had been possessed only the species aggregated shark catch data in the period between 1975 and 1993, and blue shark specific catch data were only available since 1994. The extractions of the blue shark only catch data are conducted for the log-book of Knkai and Enyo fleets separately. In both case, the model created by explanatory variables only available for the data set before 1994 has similar robustness to the one by explanatory variables available not only for the data set before 1994 but for the data set after 1994, and also it has apparently higher robustness than the model created by the single explanatory variables of the reporting ratio. Thus, the model created by explanatory variables only available for the data set before 1994 are recognized to produce the reliable extraction of blue shark only catch from the species aggregated shark catch in the log-book of 1975-1993. The results of this study also indicated the extraction method used in the previous study results in the overestimation of the blue shark catch as they only used data obtained from High blue shark CPUE areas.

Introduction

Time series, however, of stock specific total annual catch is one of the fundamental information of the stock assessment and the management of fishery catching this stock, failure of its estimation often causes overexploitation of fish stocks and hinder the recovery of fish populations and ecosystems (Agnew et. al., 2009; Hopkins and Lassen, 2008). In the case of pelagic sharks, poor condition of reliable estimations of fleet, gear, species specific catch have been hindered to obtain reasonable results of stock assessment simply because they have been treated as “by-catch” for many fisheries (e.g., ICCAT, 2009).

The log-book data of Japanese longliners had been possessed only the species aggregated shark catch data in the period between 1975 and 1993, and blue shark specific catch data were only available since 1994. Nakano and Clarke (2006) reported that species aggregated sharks catch of the set with equal to/large than 80 % of positive catch ratio of sharks per trip can be assumed to the catch of blue shark in the Atlantic in the period before 1994, and they successfully estimated abundance index with this assumption. In the case of north Pacific blue shark, the estimation of the time series of annual catches by fleet was conducted as the cooperative studies of United States and Japan for the input of stock analysis models, but results were not so stable (Kleiber et. al., 2005). One of the possible reasons of this supposed to be in the too simple method of the estimation of annual catch by Japanese longliners. They applied same method used in the Atlantic for the estimation of annual catch by Japanese longliners, but different from the Atlantic, multiple types of longline fleets are operating in the north Pacific such as distant-water and offshore tuna longliners and surface longliners, and the way of utilization of sharks could be different among these fleets

The problem of the filtering method would be no considerations except positive catch rate. It is obvious that other factors should affect the blue shark catch such as oceanic environment. Moreover the low abundance areas of blue shark are excluded as Hiraoka et al. (2011) indicated. In this study, all available information of the log-book of Japanese longliners in the period before 1994 applied to estimate blue shark specific catch from the shark species composition information in the log-book after 1993.

Materials and Methods

Data set

Catch and effort data used in this analysis was provided from the Japanese longline fishery statics compiled at the National Research Institute of Far Seas Fisheries for 1975-2010. The focused area is north side of to 60N. This data has the information of catch number, number of hooks, gear configuration, i.e. the number of branch lines between floats (hooks par baskets: HPB), sea surface temperature (SST: only after 1994) and location of set as 1x1 degree resolution. The data, which HPB is smaller than 3 and larger than 21, are removed from the analysis. In the period before 1994, the log-book records only contain species aggregated catch of shark under the column of "sharks". In the period after 1993, the log-book records contain catch of blue shark, shortfin mako shark, salmon shark, thresher sharks (since the end of 1990s), oceanic whitetip shark (since the end of the 1990s) and other sharks. Before the end of the 1990s, catch of thresher sharks and oceanic whitetip shark are reported under the column of other sharks. The percentages of operations with positive catch of blue shark in a cruise are calculated after 1994 to treat them as positive catch ratio in the analysis.

Model

Considering the vertical and horizontal distribution pattern and migrate behaviors of blue shark, the ratio of blue shark to the species aggregated catch of sharks should be changed by area, season, oceanographic conditions as well as target species of the set. In addition to this, Hiraoka et al. (2011) indicated the vessel register prefecture (as the proxy of sales strategy of sharks) has effect on the ratio of blue shark. By considering these things, one statistical model was developed to estimate the relationships between the ratio of blue shark and these factors mentioned above, and the relationships were estimated using the data after 1993. The estimated relationships were directly applied on the species aggregated "sharks" data in the period before 1994 to extract blue shark only catches. The models which to analyze data between 1994 and 2010 to obtain ratio of blue shark to the species aggregated sharks catch, and the results of this model estimation are used to extract catches from the reported species aggregated shark catch data between 1975 and 1993.
The ratio of blue shark caught by Kinkai and Enyo were estimated separately as they have different landing strategy of sharks (Hiraoka et al., 2011). The basic formula of the model is as follows;

$$Blue\ Shark\ Catch\ Ratio \sim SST + poly(lon,2) + poly(lat,2) + season + prefecture + HPB + PCR + \varepsilon$$

Here *poly*, *season*, *prefecture* and *PCR* means orthogonal polynomials, season factors i.e. 1: Jan.-Mar. 2: Apr.-Jun. 3: Jul-Sep. and 4: Oct.-Dec., prefecture code i.e. for the model of offshore longliners, 1:Hokkaido and Tohoku, 2: Oita and 3: others, for the model of distant-water longliners, 1: Hokkaido and Tohoku, 2: Kagoshima and 3: others and positive catch ratio in a cruise, respectively. In this model binomial error distribution is assumed.

The selection of factors and their two way interactions which have significant effects are estimated by both direction step-wise methods using AIC as evaluated criteria. We recognized that selected models using data after 1993 are the optimal models as the statistical diagnosis indicates that it is best fitted to the data. Because no information of SST is available for the data before 1994, the formulas selected under the condition without SST factor is recognized the available models. In addition, simple models are developed only using data of the cruise with higher positive catch than 80% to compare the results of this study to the simple one by Kleiber et al. (2009). Overall 6 models are estimated, i.e. Kinkai optimal model, Kinkai available model, Kinkai simple model, Enyo optimal model, Enyo available model and Enyo simple model.

Results and Discussions

The statistical diagnosis of the three model runs (optimal, available and simple) using the data of 1994–2010 shows the fact that available model, which is to be used for the estimation of blue shark catch of 1975–1993, has similar robustness as the optimal model for both Enyo and Kinkai data sets (Table 1). In the results of analysis of both Enyo and Kinkai data sets, the values of residual deviance and AIC of the available models are slightly larger than the optimal but much lower than the simple while the values of the degree of freedom are more or less the same among three models. Although SST is significant variable both Kinkai and Enyo (Tables 2-3), available models (almost same as the optimal model without SST) are still rather low AIC values than that of simple model. Thus, the available model could extract blue shark only catch more accurately than the simple model. This means that the results of the available model is also more accurate than the ones by Kleiber et al. (2009), as the information used by Kleiber et al. (2009) is same as the simple model but the amount of information is smaller (limited to more than 80% reporting ratio).

The annual catches of blue shark in the period of 1975–1993 estimated by the available model, by simple model and by Kleiber et al. (2009) showed the generally similar trends, and the estimates by available model produced the lowest values and the one by Kleiber et al. (2009) was highest for both Kinkai and Enyo data set (Figure 1). The extracted catches by filtering method utilized by Kleiber et al. (2009) were considered overestimate. This is because operations with higher positive catch than 80 % tend to report high proportion of blue shark in the shark species compositions (Hiraoka et al., 2011). The positive catch rate is one of the most important variables for the estimation of blue shark catch ratio of both Kinkai and Enyo data sets (Tables 2-3). Therefore the general trends of the estimated catches of blue shark were similar among the three models.

Blue shark is most popular pelagic sharks among the shark catch of Japanese longliners in the north Pacific, and its highest CPUE observed in the relatively higher latitude where Japanese shallow sets seasonally targets blue shark (Yokawa and Ando, 2011; Hiraoka et al., 2011). This draw the facts that most of observation with higher than 80 % positive catch ratio of sharks appears in/around the blue shark fishing ground of Japanese shallow sets. Thus, if one estimates the total catch of blue shark caught by Japanese longliners in the north Pacific using only data of high positive catch ratio, the results should become higher than the actual.

The available model, which is used to extract the blue shark only catch from the species aggregated catch in the log-book during 1975–1993, incorporate explanatory variables of longitude, latitude, season, prefecture and hooks per basket to account for the complex migration and distribution pattern of blue shark as well as the complex operational pattern of Japanese longliners, and the results of the analysis show that all these variables have significant effects on the extraction. In addition, the data sets of Kinkai and Enyo fleets analyzed separately because the landing strategy of sharks are rather different between two (Yokawa and Ando 2011; Hiraoka et al., 2011). In general, Kinkai fleet unloads sharks as fresh but Enyo fleet unloads shark as frozen, and market value of fresh and frozen shark are different even for the same species. Considering things written above, the results by the available model developed in this study are believed to produce the most reliable extracts of the blue shark only catch in the period between 1975 and 1993.

Although the available models are considered to be the best method to extract blue shark catch from the species aggregated shark catch at the present moment, the method used in this study demands the assumption that the operation pattern of Japanese pelagic longliners and blue shark distribution pattern have not change throughout the period analyzed (between 1975 and 2010). It is necessary to verify this assumption in some way (e.g. interviewing the fisher man) in the future. Besides the model forms should be improved because even the results of the optimal models indicate overdispersions. One of the reasons of this overdispresions is considered to be in the shortage of the explanatory variables incorporated, so exploration of available information should also be done in the future.

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Table 1 Residual deviances and AIC values of each models

Fleet type		Residual deviance	Resisual d.f.	AIC
Kinkai				
	Optimal model	662152	97167	804388
	Available model	733652	97180	875862
	Simple model	1026523	97237	1168620
Enyo				
	Optimal model	532619	89411	598877
	Available model	536118	89423	602352
	Simple model	843441	89480	909561

Table 2. Output of Type II analysis for the Kinkai Optimal model

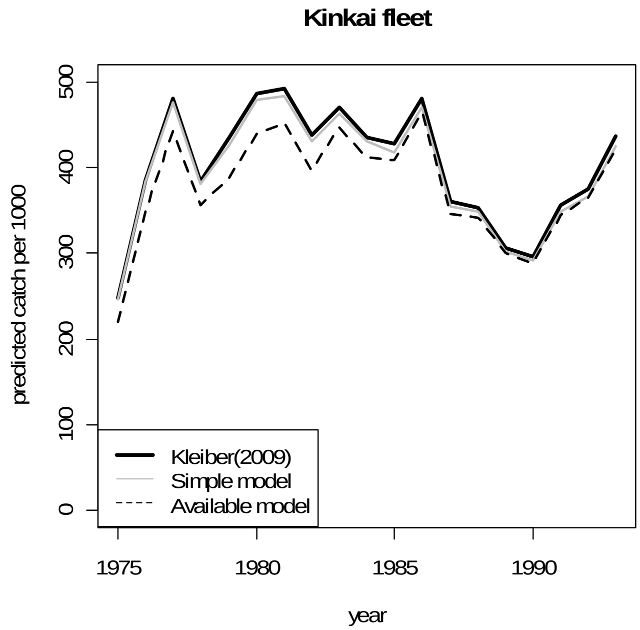
Analysis of Deviance Table (TypeII tests)

	LR Chisq	Df	Pr(>Chisq)	LR Chisq/Df
Pcr	8645	1	< 2.2e-16	8645
Sst	35416	1	< 2.2e-16	35416
poly(lon, 2)	64577	2	< 2.2e-16	32289
poly(lat, 2)	13016	2	< 2.2e-16	6508
as.factor(qt)	4633	3	< 2.2e-16	1544
as.factor(prefecture)	41	2	1.49E-09	21
as.factor(hpbc)	1490	1	< 2.2e-16	1490
pcr:sst	51	1	8.99E-13	51
pcr:poly(lon, 2)	236	2	< 2.2e-16	118
pcr:poly(lat, 2)	451	2	< 2.2e-16	226
pcr:as.factor(qt)	805	3	< 2.2e-16	268
pcr:as.factor(prefecture)	692	2	< 2.2e-16	346
pcr:as.factor(hpbc)	28	1	1.33E-07	28
sst:poly(lon, 2)	641	2	< 2.2e-16	321
sst:poly(lat, 2)	20738	2	< 2.2e-16	10369
sst:as.factor(qt)	2962	3	< 2.2e-16	987
sst:as.factor(prefecture)	936	2	< 2.2e-16	468
sst:as.factor(hpbc)	258	1	< 2.2e-16	258
poly(lon, 2):poly(lat, 2)	34439	4	< 2.2e-16	8610
poly(lon, 2):as.factor(qt)	23935	6	< 2.2e-16	3989
poly(lon, 2):as.factor(prefecture)	350	4	< 2.2e-16	88
poly(lon, 2):as.factor(hpbc)	56	2	7.98E-13	28
poly(lat, 2):as.factor(qt)	4688	6	< 2.2e-16	781
poly(lat, 2):as.factor(prefecture)	243	4	< 2.2e-16	61
poly(lat, 2):as.factor(hpbc)	7810	2	< 2.2e-16	3905
as.factor(qt):as.factor(prefecture)	189	6	< 2.2e-16	32
as.factor(qt):as.factor(hpbc)	242	3	< 2.2e-16	81
as.factor(prefecture):as.factor(hpbc	358	1	< 2.2e-16	358

Table 3. Output of Type II analysis for the Enyo Optimal model

Analysis of Deviance Table (Type II tests)

	LR Chisq	Df	Pr(>Chisq)	LR Chisq/Df
pcr	42082	1	< 2.2e-16	42082
sst	432	1	< 2.2e-16	432
poly(lon, 2)	2683	2	< 2.2e-16	1342
poly(lat, 2)	4721	2	< 2.2e-16	2361
as.factor(qt)	942	3	< 2.2e-16	314
as.factor(prefecture)	41131	2	< 2.2e-16	20566
as.factor(hpbc)	30422	1	< 2.2e-16	30422
pcr:sst	32	1	1.38E-08	32
pcr:poly(lon, 2)	1143	2	< 2.2e-16	572
pcr:poly(lat, 2)	4367	2	< 2.2e-16	2184
pcr:as.factor(qt)	1193	3	< 2.2e-16	398
pcr:as.factor(prefecture)	4698	2	< 2.2e-16	2349
sst:poly(lon, 2)	234	2	< 2.2e-16	117
sst:poly(lat, 2)	1215	2	< 2.2e-16	608
sst:as.factor(qt)	549	3	< 2.2e-16	183
sst:as.factor(prefecture)	465	2	< 2.2e-16	233
sst:as.factor(hpbc)	133	1	< 2.2e-16	133
poly(lon, 2):poly(lat, 2)	9270	4	< 2.2e-16	2318
poly(lon, 2):as.factor(qt)	846	6	< 2.2e-16	141
poly(lon, 2):as.factor(prefecture)	1942	4	< 2.2e-16	486
poly(lon, 2):as.factor(hpbc)	1486	2	< 2.2e-16	743
poly(lat, 2):as.factor(qt)	2928	6	< 2.2e-16	488
poly(lat, 2):as.factor(prefecture)	8401	4	< 2.2e-16	2100
poly(lat, 2):as.factor(hpbc)	4917	2	< 2.2e-16	2459
as.factor(qt):as.factor(prefecture)	3335	6	< 2.2e-16	556
as.factor(qt):as.factor(hpbc)	3076	3	< 2.2e-16	1025
as.factor(prefecture):as.factor(hpbc)	1741	1	< 2.2e-16	1741



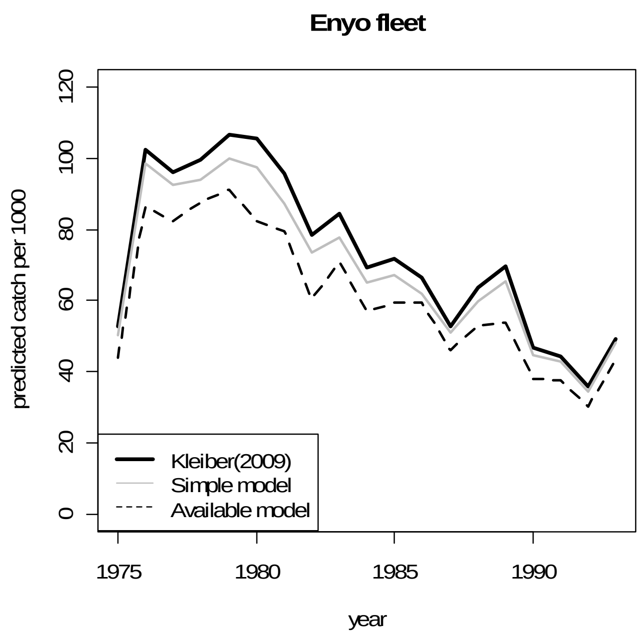


Figure 1 Predicted catch of blue shark estimated by each models by Kinkai fleet (upper) and Enyo fleet (lower) in the North Pacific during 1975 to 1993.

Appendix: Summary outputs of GLM analyses from R

Kinkai Optimal model

```
Call:
glm(formula = cbind(blshrk, osharks) ~ (pcr + sst + poly(lon,
    2) + poly(lat, 2) + as.factor(qt) + as.factor(prefecture) + as.factor(hpbc))^2,
    family = binomial, data = kdata)

Deviance Residuals:
   Min      1Q  Median      3Q     Max
-52.44    0.00    0.00    0.00   28.92

Coefficients: (1 not defined because of singularities)
                                   Estimate Std. Error z value Pr(>|z|)
(Intercept)                      -1.038e+01  3.788e-01 -27.413  < 2e-16 ***
pcr                               5.454e+00  3.651e-01  14.938  < 2e-16 ***
sst                               2.842e-02  1.610e-03  17.653  < 2e-16 ***
poly(lon, 2)1                     2.702e+02  2.958e+01   9.133  < 2e-16 ***
poly(lon, 2)2                    -4.745e+02  3.580e+01 -13.254  < 2e-16 ***
poly(lat, 2)1                     6.601e+03  9.677e+01  68.211  < 2e-16 ***
poly(lat, 2)2                    -3.129e+03  4.134e+01 -75.683  < 2e-16 ***
as.factor(qt)2                   -5.832e+00  1.807e-01 -32.279  < 2e-16 ***
as.factor(qt)3                   -3.666e+00  1.945e-01 -18.850  < 2e-16 ***
as.factor(qt)4                   -8.654e-01  1.912e-01  -4.525 6.03e-06 ***
as.factor(prefecture)2            5.501e-01  2.477e+00   0.222 0.824270
as.factor(prefecture)3            1.155e+01  2.920e-01  39.561  < 2e-16 ***
as.factor(hpbc)2                  2.967e+00  1.569e-01  18.912  < 2e-16 ***
pcr:sst                          -1.152e-02  1.549e-03  -7.441 1.00e-13 ***
pcr:poly(lon, 2)1                -3.567e+01  2.649e+01  -1.347 0.178140
pcr:poly(lon, 2)2                 4.954e+02  3.273e+01  15.137  < 2e-16 ***
pcr:poly(lat, 2)1                -1.096e+03  5.842e+01 -18.766  < 2e-16 ***
pcr:poly(lat, 2)2                 4.511e+02  3.057e+01  14.754  < 2e-16 ***
pcr:as.factor(qt)2                3.689e+00  1.658e-01  22.254  < 2e-16 ***
pcr:as.factor(qt)3                2.711e+00  1.794e-01  15.114  < 2e-16 ***
pcr:as.factor(qt)4                7.647e-01  1.612e-01   4.745 2.08e-06 ***
pcr:as.factor(prefecture)2        3.557e-01  3.950e-01   0.900 0.367952
pcr:as.factor(prefecture)3       -4.617e+00  1.873e-01 -24.646  < 2e-16 ***
pcr:as.factor(hpbc)2              6.343e-01  1.193e-01   5.317 1.05e-07 ***
sst:poly(lon, 2)1                -1.141e+00  4.543e-02 -25.108  < 2e-16 ***
sst:poly(lon, 2)2                 1.960e-01  5.596e-02   3.503 0.000460 ***
sst:poly(lat, 2)1                -1.139e+01  3.143e-01 -36.244  < 2e-16 ***
sst:poly(lat, 2)2                 9.905e+00  1.134e-01  87.305  < 2e-16 ***
sst:as.factor(qt)2                1.125e-02  3.812e-04  29.507  < 2e-16 ***
sst:as.factor(qt)3                9.135e-03  4.129e-04  22.123  < 2e-16 ***
sst:as.factor(qt)4                5.721e-04  4.431e-04   1.291 0.196610
sst:as.factor(prefecture)2        9.158e-03  9.383e-03   0.976 0.329029
sst:as.factor(prefecture)3       -2.994e-02  9.953e-04 -30.086  < 2e-16 ***
sst:as.factor(hpbc)2             -3.927e-03  2.513e-04 -15.629  < 2e-16 ***
poly(lon, 2)1:poly(lat, 2)1       1.031e+05  8.114e+03  12.702  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)1      -3.453e+04  6.619e+03  -5.217 1.81e-07 ***
poly(lon, 2)1:poly(lat, 2)2       1.659e+05  2.774e+03  59.787  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)2      -5.178e+04  2.511e+03 -20.619  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)2      2.162e+02  4.114e+00  52.548  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)2     -2.132e+02  6.114e+00 -34.875  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)3     -1.729e+02  5.650e+00 -30.593  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)3     -9.907e+01  7.922e+00 -12.505  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)4     -3.514e+02  5.324e+00 -65.997  < 2e-16 ***
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poly(lon, 2)2:as.factor(qt)4       -2.560e+01  7.998e+00  -3.201 0.001370 **
poly(lon, 2)1:as.factor(prefecture)2     1.619e+02  9.023e+01   1.795 0.072731 .
poly(lon, 2)2:as.factor(prefecture)2     1.257e+02  7.715e+01   1.630 0.103136
poly(lon, 2)1:as.factor(prefecture)3     1.675e+02  1.567e+01  10.692  < 2e-16 ***
poly(lon, 2)2:as.factor(prefecture)3     2.980e+02  1.835e+01  16.236  < 2e-16 ***
poly(lon, 2)1:as.factor(hpbc)2      3.115e+01  8.343e+00   3.734 0.000189 ***
poly(lon, 2)2:as.factor(hpbc)2      8.257e+01  1.186e+01   6.963 3.32e-12 ***
poly(lat, 2)1:as.factor(qt)2        2.561e+02  3.251e+01   7.877 3.36e-15 ***
poly(lat, 2)2:as.factor(qt)2       -2.763e+02  1.344e+01 -20.559  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)3       -4.621e+02  3.525e+01 -13.110  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)3       -1.812e+02  1.408e+01 -12.869  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)4       -4.695e+02  5.315e+01  -8.835  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)4        1.244e+02  1.811e+01   6.869 6.45e-12 ***
poly(lat, 2)1:as.factor(prefecture)2    -1.472e+03  3.210e+02  -4.587 4.50e-06 ***
poly(lat, 2)2:as.factor(prefecture)2     1.567e+03  2.053e+02   7.632 2.31e-14 ***
poly(lat, 2)1:as.factor(prefecture)3    -4.333e+02  4.013e+01 -10.797  < 2e-16 ***
poly(lat, 2)2:as.factor(prefecture)3     2.023e+02  1.770e+01  11.434  < 2e-16 ***
poly(lat, 2)1:as.factor(hpbc)2     -1.775e+03  4.754e+01 -37.327  < 2e-16 ***
poly(lat, 2)2:as.factor(hpbc)2     -1.199e+02  1.840e+01  -6.515 7.28e-11 ***
as.factor(qt)2:as.factor(prefecture)2   -1.542e+00  4.354e-01  -3.542 0.000397 ***
as.factor(qt)3:as.factor(prefecture)2   -2.059e+00  4.130e-01  -4.986 6.16e-07 ***
as.factor(qt)4:as.factor(prefecture)2   -1.850e-01  3.518e-01  -0.526 0.599030
as.factor(qt)2:as.factor(prefecture)3    5.153e-01  7.205e-02   7.152 8.57e-13 ***
as.factor(qt)3:as.factor(prefecture)3   -1.468e-01  9.402e-02  -1.562 0.118386
as.factor(qt)4:as.factor(prefecture)3    2.010e-01  8.954e-02   2.244 0.024801 *
as.factor(qt)2:as.factor(hpbc)2     3.836e-01  3.943e-02   9.728  < 2e-16 ***
as.factor(qt)3:as.factor(hpbc)2     3.998e-01  4.179e-02   9.569  < 2e-16 ***
as.factor(qt)4:as.factor(hpbc)2     6.173e-01  4.000e-02  15.432  < 2e-16 ***
as.factor(prefecture)2:as.factor(hpbc)2         NA         NA      NA       NA
as.factor(prefecture)3:as.factor(hpbc)2 -9.402e-01  4.900e-02 -19.187  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1043482  on 97238  degrees of freedom
Residual deviance:  662152  on 97167  degrees of freedom
AIC: 804388

Number of Fisher Scoring iterations: 6
```
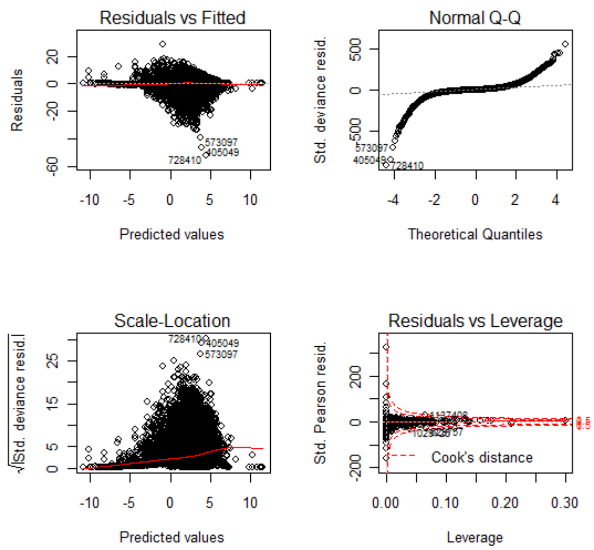



Kinkai available model

Call:
glm(formula = cbind(blshrk, osharks) ~ pcr + poly(lon, 2) +
    poly(lat, 2) + as.factor(qt) + as.factor(prefecture) + as.factor(hpbc) +
    pcr:poly(lon, 2) + pcr:poly(lat, 2) + pcr:as.factor(qt) +
    pcr:as.factor(prefecture) + poly(lon, 2):poly(lat, 2) + poly(lon,
    2):as.factor(qt) + poly(lon, 2):as.factor(prefecture) + poly(lon,
    2):as.factor(hpbc) + poly(lat, 2):as.factor(qt) + poly(lat,
    2):as.factor(prefecture) + poly(lat, 2):as.factor(hpbc) + as.factor(qt):as.factor(prefecture) +
    as.factor(qt):as.factor(hpbc) + as.factor(prefecture):as.factor(hpbc),
    family = binomial, data = ktemp)

Deviance Residuals:

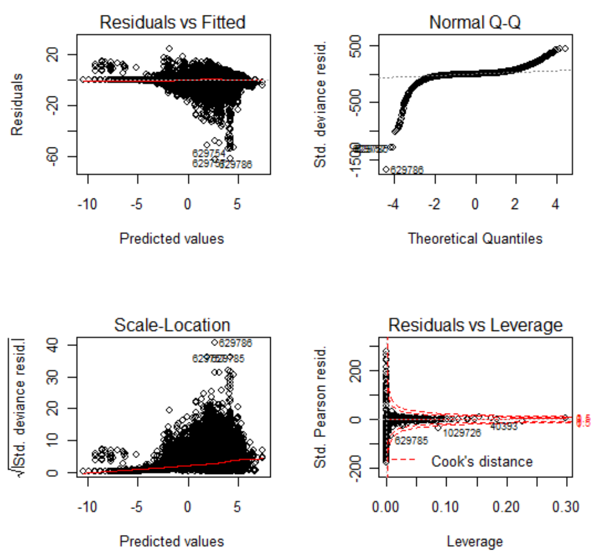
Min	1Q	Median	3Q	Max
-62.84	0.00	0.00	0.00	24.75

Coefficients: (1 not defined because of singularities)

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-7.337e+00	1.489e-01	-49.270	< 2e-16	***
pcr	3.220e+00	1.515e-01	21.247	< 2e-16	***
poly(lon, 2)1	6.043e+01	2.696e+01	2.241	0.024995	*
poly(lon, 2)2	-2.783e+02	3.191e+01	-8.720	< 2e-16	***
poly(lat, 2)1	5.671e+03	6.227e+01	91.083	< 2e-16	***
poly(lat, 2)2	-1.671e+03	3.254e+01	-51.343	< 2e-16	***
as.factor(qt)2	-2.842e+00	1.553e-01	-18.306	< 2e-16	***
as.factor(qt)3	1.485e-01	1.542e-01	0.963	0.335569	
as.factor(qt)4	-2.067e-01	1.580e-01	-1.308	0.190856	
as.factor(prefecture)2	3.851e+00	4.865e-01	7.914	2.49e-15	***
as.factor(prefecture)3	5.357e+00	1.702e-01	31.475	< 2e-16	***
as.factor(hpbc)2	5.358e+00	6.785e-02	78.967	< 2e-16	***
pcr:poly(lon, 2)1	5.817e+01	2.562e+01	2.270	0.023195	*
pcr:poly(lon, 2)2	4.233e+02	3.140e+01	13.479	< 2e-16	***
pcr:poly(lat, 2)1	-8.100e+02	4.962e+01	-16.325	< 2e-16	***
pcr:poly(lat, 2)2	3.343e+02	2.935e+01	11.389	< 2e-16	***
pcr:as.factor(qt)2	3.688e+00	1.642e-01	22.466	< 2e-16	***

```
pcr:as.factor(qt)3               1.609e+00  1.645e-01   9.780  < 2e-16 ***
pcr:as.factor(qt)4               4.922e-01  1.595e-01   3.086 0.002031 **
pcr:as.factor(prefecture)2       1.891e-01  3.744e-01   0.505 0.613383
pcr:as.factor(prefecture)3      -3.826e+00  1.666e-01 -22.968  < 2e-16 ***
poly(lon, 2)1:poly(lat, 2)1      5.567e+04  7.928e+03   7.021 2.20e-12 ***
poly(lon, 2)2:poly(lat, 2)1     -7.784e+04  5.807e+03 -13.404  < 2e-16 ***
poly(lon, 2)1:poly(lat, 2)2      1.973e+05  2.794e+03  70.616  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)2     -3.680e+04  2.328e+03 -15.807  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)2     1.564e+02  3.989e+00  39.206  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)2    -2.236e+02  6.083e+00 -36.762  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)3    -3.310e+02  5.089e+00 -65.058  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)3    -1.036e+02  7.441e+00 -13.919  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)4    -3.925e+02  5.127e+00 -76.550  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)4    -5.513e+01  7.877e+00  -6.998 2.59e-12 ***
poly(lon, 2)1:as.factor(prefecture)2     6.151e+01  8.891e+01   0.692 0.489102
poly(lon, 2)2:as.factor(prefecture)2     2.614e+02  7.517e+01   3.477 0.000508 ***
poly(lon, 2)1:as.factor(prefecture)3    -3.995e+00  1.478e+01  -0.270 0.786955
poly(lon, 2)2:as.factor(prefecture)3     2.730e+02  1.893e+01  14.420  < 2e-16 ***
poly(lon, 2)1:as.factor(hpbc)2       1.427e+02  7.325e+00  19.479  < 2e-16 ***
poly(lon, 2)2:as.factor(hpbc)2      -1.187e+02  9.682e+00 -12.259  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)2    -3.189e+02  3.180e+01 -10.030  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)2    -1.453e+02  1.393e+01 -10.431  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)3    -8.279e+02  3.274e+01 -25.292  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)3    -7.268e+01  1.414e+01  -5.139 2.77e-07 ***
poly(lat, 2)1:as.factor(qt)4    -6.659e+02  4.621e+01 -14.409  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)4     1.932e+02  1.689e+01  11.440  < 2e-16 ***
poly(lat, 2)1:as.factor(prefecture)2    -2.090e+03  2.658e+02  -7.862 3.80e-15 ***
poly(lat, 2)2:as.factor(prefecture)2     2.108e+03  1.866e+02  11.299  < 2e-16 ***
poly(lat, 2)1:as.factor(prefecture)3    -6.166e+02  3.318e+01 -18.586  < 2e-16 ***
poly(lat, 2)2:as.factor(prefecture)3     7.873e+02  1.701e+01  46.280  < 2e-16 ***
poly(lat, 2)1:as.factor(hpbc)2      -3.510e+03  4.054e+01 -86.589  < 2e-16 ***
poly(lat, 2)2:as.factor(hpbc)2       4.693e+02  1.593e+01  29.454  < 2e-16 ***
as.factor(qt)2:as.factor(prefecture)2   -1.440e+00  4.352e-01  -3.309 0.000937 ***
as.factor(qt)3:as.factor(prefecture)2   -2.275e+00  3.523e-01  -6.458 1.06e-10 ***
as.factor(qt)4:as.factor(prefecture)2   -6.444e-01  3.439e-01  -1.874 0.060963 .
as.factor(qt)2:as.factor(prefecture)3    1.064e-02  6.610e-02   0.161 0.872135
as.factor(qt)3:as.factor(prefecture)3   -1.913e+00  7.944e-02 -24.077  < 2e-16 ***
as.factor(qt)4:as.factor(prefecture)3   -5.830e-01  8.088e-02  -7.209 5.63e-13 ***
as.factor(qt)2:as.factor(hpbc)2      3.443e-01  3.700e-02   9.307  < 2e-16 ***
as.factor(qt)3:as.factor(hpbc)2      3.685e-01  3.914e-02   9.415  < 2e-16 ***
as.factor(qt)4:as.factor(hpbc)2      6.789e-01  3.856e-02  17.610  < 2e-16 ***
as.factor(prefecture)2:as.factor(hpbc)2         NA         NA      NA       NA
as.factor(prefecture)3:as.factor(hpbc)2 -1.019e+00  4.608e-02 -22.109  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1043482  on 97238  degrees of freedom
Residual deviance:  733652  on 97180  degrees of freedom
AIC: 875862

Number of Fisher Scoring iterations: 6

Analysis of Deviance Table (Type II tests)
```

```
Response: cbind(blshrk, osharks)
                             LR Chisq Df Pr(>Chisq)
pcr                               8510  1  < 2.2e-16 ***
poly(lon, 2)                      58827  2  < 2.2e-16 ***
poly(lat, 2)                      25079  2  < 2.2e-16 ***
as.factor(qt)                     10534  3  < 2.2e-16 ***
as.factor(prefecture)               263  2  < 2.2e-16 ***
as.factor(hpbc)                    4742  1  < 2.2e-16 ***
pcr:poly(lon, 2)                    212  2  < 2.2e-16 ***
pcr:poly(lat, 2)                    290  2  < 2.2e-16 ***
pcr:as.factor(qt)                   803  3  < 2.2e-16 ***
pcr:as.factor(prefecture)           579  2  < 2.2e-16 ***
poly(lon, 2):poly(lat, 2)         55939  4  < 2.2e-16 ***
poly(lon, 2):as.factor(qt)        27843  6  < 2.2e-16 ***
poly(lon, 2):as.factor(prefecture)      264  4  < 2.2e-16 ***
poly(lon, 2):as.factor(hpbc)        630  2  < 2.2e-16 ***
poly(lat, 2):as.factor(qt)         6344  6  < 2.2e-16 ***
poly(lat, 2):as.factor(prefecture)     2352  4  < 2.2e-16 ***
poly(lat, 2):as.factor(hpbc)      13609  2  < 2.2e-16 ***
as.factor(qt):as.factor(prefecture)     1083  6  < 2.2e-16 ***
as.factor(qt):as.factor(hpbc)       320  3  < 2.2e-16 ***
as.factor(prefecture):as.factor(hpbc)     469  1  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '
```



Kinkai Simple model

```
Call:
glm(formula = cbind(blshrk, osharks) ~ pcr, family = binomial,
    data = ktemp)

Deviance Residuals:
   Min      1Q  Median      3Q     Max
-69.74    0.00    0.00    0.00   13.09

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
```

(Intercept) -1.24936   0.03045 -41.03   <2e-16 ***
pcr   4.67170   0.03076 151.90   <2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

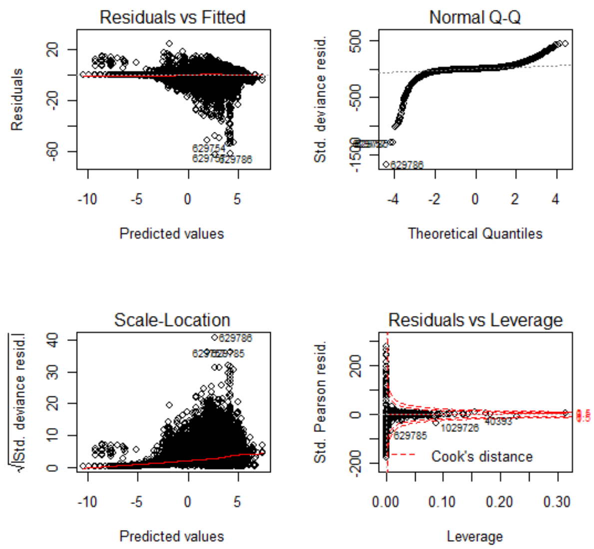
    Null deviance: 1043482 on 97238 degrees of freedom
Residual deviance: 1026523 on 97237 degrees of freedom
AIC: 1168620

Number of Fisher Scoring iterations: 5

Analysis of Deviance Table (Type II tests)

Response: cbind(blshrk, osharks)
    LR Chisq Df Pr(>Chisq)
pcr   16959 1 < 2.2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

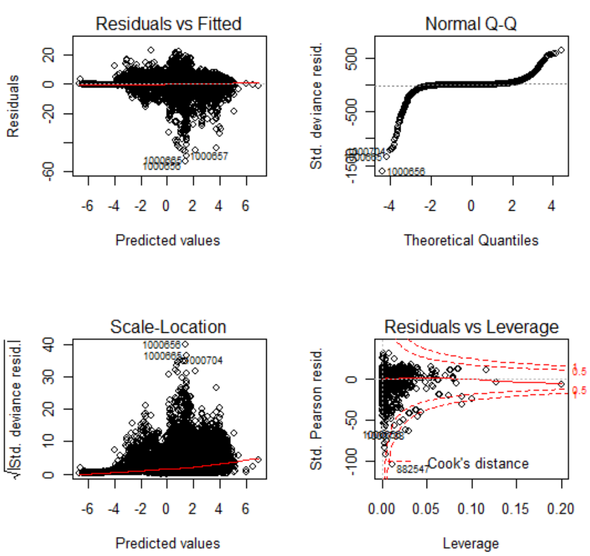


Enyo Optimal model
Call:
glm(formula = cbind(blshrk, osharks) ~ pcr + sst + poly(lon,
    2) + poly(lat, 2) + as.factor(qt) + as.factor(prefecture) + as.factor(hpbc) +
    pcr:sst + pcr:poly(lon, 2) + pcr:poly(lat, 2) +
    pcr:as.factor(qt) + pcr:as.factor(prefecture) + sst:poly(lon,
    2) + sst:poly(lat, 2) + sst:as.factor(qt) + sst:as.factor(prefecture) +
    sst:as.factor(hpbc) + poly(lon, 2):poly(lat, 2) + poly(lon,
    2):as.factor(qt) + poly(lon, 2):as.factor(prefecture) + poly(lon,
    2):as.factor(hpbc) + poly(lat, 2):as.factor(qt) + poly(lat,
    2):as.factor(prefecture) + poly(lat, 2):as.factor(hpbc) + as.factor(qt):as.factor(prefecture) +
    as.factor(qt):as.factor(hpbc) + as.factor(prefecture):as.factor(hpbc),
    family = binomial, data = edata)

Deviance Residuals:

```
   Min      1Q  Median      3Q     Max
-53.63    0.00    0.00    0.00   23.55

Coefficients: (1 not defined because of singularities)
                                  Estimate Std. Error z value Pr(>|z|)
(Intercept)                     -4.988e+00  1.942e-01 -25.680  < 2e-16 ***
pcr                              5.533e+00  1.762e-01  31.398  < 2e-16 ***
sst                             -2.462e-03  7.312e-04  -3.367 0.000761 ***
poly(lon, 2)1                   -1.843e+02  2.791e+01  -6.604 4.01e-11 ***
poly(lon, 2)2                    2.148e+02  1.638e+01  13.114  < 2e-16 ***
poly(lat, 2)1                   -1.350e+02  3.959e+01  -3.411 0.000647 ***
poly(lat, 2)2                    6.179e+02  1.791e+01  34.511  < 2e-16 ***
as.factor(qt)2                  -3.564e-01  9.841e-02  -3.621 0.000293 ***
as.factor(qt)3                   4.321e-01  1.061e-01   4.073 4.63e-05 ***
as.factor(qt)4                  -2.175e+00  1.307e-01 -16.632  < 2e-16 ***
as.factor(prefecture)3           2.959e+00  7.383e-02  40.077  < 2e-16 ***
as.factor(prefecture)4           4.834e+00  1.822e-01  26.531  < 2e-16 ***
as.factor(hpbc)2                 1.080e+00  9.531e-02  11.331  < 2e-16 ***
pcr:sst                         -3.852e-03  6.882e-04  -5.597 2.18e-08 ***
pcr:poly(lon, 2)1                4.382e+02  1.419e+01  30.878  < 2e-16 ***
pcr:poly(lon, 2)2               -2.190e+02  1.158e+01 -18.916  < 2e-16 ***
pcr:poly(lat, 2)1                1.231e+03  1.824e+01  67.486  < 2e-16 ***
pcr:poly(lat, 2)2               -1.636e+02  1.108e+01 -14.762  < 2e-16 ***
pcr:as.factor(qt)2              -3.957e-01  5.891e-02  -6.716 1.86e-11 ***
pcr:as.factor(qt)3              -1.718e+00  5.956e-02 -28.841  < 2e-16 ***
pcr:as.factor(qt)4              -3.716e-01  6.884e-02  -5.398 6.74e-08 ***
pcr:as.factor(prefecture)3      -3.175e+00  4.730e-02 -67.126  < 2e-16 ***
pcr:as.factor(prefecture)4      -2.182e+00  7.882e-02 -27.684  < 2e-16 ***
sst:poly(lon, 2)1                5.406e-01  8.291e-02   6.520 7.01e-11 ***
sst:poly(lon, 2)2                6.404e-01  4.529e-02  14.141  < 2e-16 ***
sst:poly(lat, 2)1                3.528e-01  1.053e-01   3.351 0.000806 ***
sst:poly(lat, 2)2               -1.555e+00  4.558e-02 -34.127  < 2e-16 ***
sst:as.factor(qt)2               6.267e-03  3.194e-04  19.625  < 2e-16 ***
sst:as.factor(qt)3               3.176e-03  3.415e-04   9.301  < 2e-16 ***
sst:as.factor(qt)4               6.703e-03  4.425e-04  15.146  < 2e-16 ***
sst:as.factor(prefecture)3       2.007e-03  2.308e-04   8.696  < 2e-16 ***
sst:as.factor(prefecture)4      -1.215e-02  6.745e-04 -18.019  < 2e-16 ***
sst:as.factor(hpbc)2             3.617e-03  3.088e-04  11.710  < 2e-16 ***
poly(lon, 2)1:poly(lat, 2)1     -1.038e+05  3.194e+03 -32.505  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)1     -8.275e+03  1.839e+03  -4.499 6.82e-06 ***
poly(lon, 2)1:poly(lat, 2)2      9.987e+04  1.738e+03  57.450  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)2     -5.516e+03  8.998e+02  -6.130 8.81e-10 ***
poly(lon, 2)1:as.factor(qt)2    -7.828e+01  6.329e+00 -12.370  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)2    -1.142e+01  4.077e+00  -2.800 0.005107 **
poly(lon, 2)1:as.factor(qt)3     7.734e+01  6.415e+00  12.055  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)3     1.743e+01  4.749e+00   3.670 0.000242 ***
poly(lon, 2)1:as.factor(qt)4     6.355e+01  6.125e+00  10.376  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)4    -1.129e+01  5.081e+00  -2.221 0.026323 *
poly(lon, 2)1:as.factor(prefecture)3   -1.224e+02  4.882e+00 -25.071  < 2e-16 ***
poly(lon, 2)2:as.factor(prefecture)3    4.133e+01  2.544e+00  16.248  < 2e-16 ***
poly(lon, 2)1:as.factor(prefecture)4    5.403e+01  1.107e+01   4.883 1.05e-06 ***
poly(lon, 2)2:as.factor(prefecture)4    1.631e+02  6.870e+00  23.739  < 2e-16 ***
poly(lon, 2)1:as.factor(hpbc)2  -3.238e+02  1.264e+01 -25.623  < 2e-16 ***
poly(lon, 2)2:as.factor(hpbc)2  -2.789e+02  7.319e+00 -38.105  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)2    -1.422e+02  1.082e+01 -13.143  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)2     1.542e+01  6.314e+00   2.442 0.014586 *
```

```
poly(lat, 2)1:as.factor(qt)3        2.785e+02  1.036e+01  26.883  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)3       -1.320e+02  5.953e+00 -22.178  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)4        2.257e+02  1.129e+01  19.999  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)4       -8.209e+01  6.196e+00 -13.248  < 2e-16 ***
poly(lat, 2)1:as.factor(prefecture)3    -4.265e+02  7.409e+00 -57.561  < 2e-16 ***
poly(lat, 2)2:as.factor(prefecture)3    -1.426e+02  3.340e+00 -42.710  < 2e-16 ***
poly(lat, 2)1:as.factor(prefecture)4     1.582e+02  2.599e+01   6.086 1.16e-09 ***
poly(lat, 2)2:as.factor(prefecture)4    -1.927e+02  1.770e+01 -10.891  < 2e-16 ***
poly(lat, 2)1:as.factor(hpbc)2      -7.559e+02  2.803e+01 -26.972  < 2e-16 ***
poly(lat, 2)2:as.factor(hpbc)2      -1.744e+02  8.057e+00 -21.646  < 2e-16 ***
as.factor(qt)2:as.factor(prefecture)3   -6.895e-01  1.728e-02 -39.910  < 2e-16 ***
as.factor(qt)3:as.factor(prefecture)3   -4.289e-01  2.123e-02 -20.200  < 2e-16 ***
as.factor(qt)4:as.factor(prefecture)3    1.843e-01  2.073e-02   8.887  < 2e-16 ***
as.factor(qt)2:as.factor(prefecture)4    3.306e-02  4.827e-02   0.685 0.493450
as.factor(qt)3:as.factor(prefecture)4    7.450e-02  5.056e-02   1.474 0.140600
as.factor(qt)4:as.factor(prefecture)4    3.460e-01  5.648e-02   6.126 9.00e-10 ***
as.factor(qt)2:as.factor(hpbc)2     -8.652e-01  2.972e-02 -29.108  < 2e-16 ***
as.factor(qt)3:as.factor(hpbc)2      5.845e-01  3.446e-02  16.962  < 2e-16 ***
as.factor(qt)4:as.factor(hpbc)2      7.079e-01  3.009e-02  23.526  < 2e-16 ***
as.factor(prefecture)3:as.factor(hpbc)2 -8.824e-01  2.150e-02 -41.051  < 2e-16 ***
as.factor(prefecture)4:as.factor(hpbc)2         NA         NA      NA       NA
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1039281  on 89481  degrees of freedom
Residual deviance:  532619  on 89411  degrees of freedom
AIC: 598877

Number of Fisher Scoring iterations: 6
```



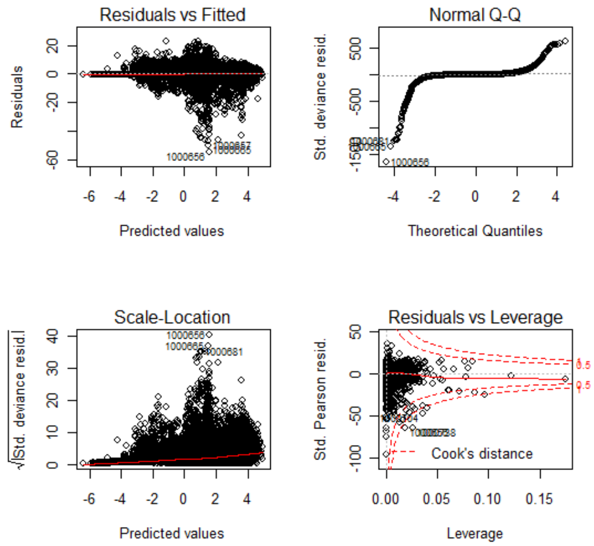
Enyo Available model

```
Call:
glm(formula = cbind(blshrk, osharks) ~ pcr + poly(lon, 2) +
    poly(lat, 2) + as.factor(qt) + as.factor(prefecture) + as.factor(hpbc) +
```

```
    pcr:poly(lon, 2) + pcr:poly(lat, 2) + pcr:as.factor(qt) +
    pcr:as.factor(prefecture) + poly(lon, 2):poly(lat, 2) + poly(lon,
    2):as.factor(qt) + poly(lon, 2):as.factor(prefecture) + poly(lon,
    2):as.factor(hpbc) + poly(lat, 2):as.factor(qt) + poly(lat,
    2):as.factor(prefecture) + poly(lat, 2):as.factor(hpbc) + as.factor(qt):as.factor(prefecture) +
    as.factor(qt):as.factor(hpbc) + as.factor(prefecture):as.factor(hpbc),
    family = binomial, data = etemp)

Deviance Residuals:
   Min      1Q  Median      3Q     Max
-55.21    0.00    0.00    0.00   23.20

Coefficients: (1 not defined because of singularities)
                                        Estimate Std. Error z value Pr(>|z|)
(Intercept)                           -5.624e+00  8.402e-02 -66.934  < 2e-16 ***
pcr                                    4.600e+00  4.781e-02  96.208  < 2e-16 ***
poly(lon, 2)1                         -3.091e+01  1.726e+01  -1.791 0.073254 .
poly(lon, 2)2                          4.064e+02  1.251e+01  32.489  < 2e-16 ***
poly(lat, 2)1                          2.287e+01  2.944e+01   0.777 0.437377
poly(lat, 2)2                          2.651e+02  1.338e+01  19.812  < 2e-16 ***
as.factor(qt)2                         1.322e+00  5.815e-02  22.731  < 2e-16 ***
as.factor(qt)3                         1.086e+00  5.959e-02  18.229  < 2e-16 ***
as.factor(qt)4                        -6.070e-01  6.836e-02  -8.879  < 2e-16 ***
as.factor(prefecture)3                 3.325e+00  4.840e-02  68.704  < 2e-16 ***
as.factor(prefecture)4                 1.691e+00  7.640e-02  22.136  < 2e-16 ***
as.factor(hpbc)2                       2.021e+00  7.202e-02  28.067  < 2e-16 ***
pcr:poly(lon, 2)1                      4.664e+02  1.364e+01  34.203  < 2e-16 ***
pcr:poly(lon, 2)2                     -2.318e+02  1.148e+01 -20.198  < 2e-16 ***
pcr:poly(lat, 2)1                      1.286e+03  1.486e+01  86.532  < 2e-16 ***
pcr:poly(lat, 2)2                     -1.314e+02  1.084e+01 -12.124  < 2e-16 ***
pcr:as.factor(qt)2                    -5.045e-01  5.810e-02  -8.683  < 2e-16 ***
pcr:as.factor(qt)3                    -1.801e+00  5.804e-02 -31.036  < 2e-16 ***
pcr:as.factor(qt)4                    -3.423e-01  6.851e-02  -4.997 5.82e-07 ***
pcr:as.factor(prefecture)3            -3.091e+00  4.703e-02 -65.718  < 2e-16 ***
pcr:as.factor(prefecture)4            -2.213e+00  7.810e-02 -28.329  < 2e-16 ***
poly(lon, 2)1:poly(lat, 2)1           -1.171e+05  2.562e+03 -45.703  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)1           -2.549e+04  1.741e+03 -14.638  < 2e-16 ***
poly(lon, 2)1:poly(lat, 2)2            7.936e+04  1.634e+03  48.580  < 2e-16 ***
poly(lon, 2)2:poly(lat, 2)2           -1.058e+04  8.757e+02 -12.082  < 2e-16 ***
poly(lon, 2)1:as.factor(qt)2          -8.823e+01  6.190e+00 -14.254  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)2          -1.184e+01  4.045e+00  -2.927 0.003422 **
poly(lon, 2)1:as.factor(qt)3           8.782e+01  5.943e+00  14.778  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)3           1.989e+01  4.531e+00   4.390 1.13e-05 ***
poly(lon, 2)1:as.factor(qt)4           5.085e+01  5.871e+00   8.661  < 2e-16 ***
poly(lon, 2)2:as.factor(qt)4          -1.800e+01  5.026e+00  -3.581 0.000343 ***
poly(lon, 2)1:as.factor(prefecture)3  -1.364e+02  4.666e+00 -29.235  < 2e-16 ***
poly(lon, 2)2:as.factor(prefecture)3   3.431e+01  2.487e+00  13.793  < 2e-16 ***
poly(lon, 2)1:as.factor(prefecture)4   9.685e+01  1.062e+01   9.120  < 2e-16 ***
poly(lon, 2)2:as.factor(prefecture)4   1.690e+02  6.761e+00  24.996  < 2e-16 ***
poly(lon, 2)1:as.factor(hpbc)2        -3.883e+02  1.213e+01 -32.002  < 2e-16 ***
poly(lon, 2)2:as.factor(hpbc)2        -3.001e+02  7.113e+00 -42.185  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)2          -2.481e+02  8.757e+00 -28.338  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)2          -2.497e+01  6.137e+00  -4.069 4.72e-05 ***
poly(lat, 2)1:as.factor(qt)3           2.380e+02  7.760e+00  30.664  < 2e-16 ***
poly(lat, 2)2:as.factor(qt)3          -1.664e+02  5.695e+00 -29.224  < 2e-16 ***
poly(lat, 2)1:as.factor(qt)4           1.220e+02  8.059e+00  15.133  < 2e-16 ***
```

```
poly(lat, 2)2:as.factor(qt)4        -1.014e+02  5.835e+00 -17.380  < 2e-16 ***
poly(lat, 2)1:as.factor(prefecture)3    -4.505e+02  6.146e+00 -73.300  < 2e-16 ***
poly(lat, 2)2:as.factor(prefecture)3    -1.495e+02  3.289e+00 -45.460  < 2e-16 ***
poly(lat, 2)1:as.factor(prefecture)4     3.158e+02  2.462e+01  12.828  < 2e-16 ***
poly(lat, 2)2:as.factor(prefecture)4    -1.905e+02  1.768e+01 -10.773  < 2e-16 ***
poly(lat, 2)1:as.factor(hpbc)2      -8.528e+02  2.641e+01 -32.292  < 2e-16 ***
poly(lat, 2)2:as.factor(hpbc)2      -2.088e+02  7.358e+00 -28.375  < 2e-16 ***
as.factor(qt)2:as.factor(prefecture)3   -6.664e-01  1.713e-02 -38.905  < 2e-16 ***
as.factor(qt)3:as.factor(prefecture)3   -3.173e-01  1.996e-02 -15.897  < 2e-16 ***
as.factor(qt)4:as.factor(prefecture)3    2.703e-01  2.049e-02  13.191  < 2e-16 ***
as.factor(qt)2:as.factor(prefecture)4   -2.041e-02  4.770e-02  -0.428 0.668692
as.factor(qt)3:as.factor(prefecture)4    5.553e-02  4.996e-02   1.112 0.266313
as.factor(qt)4:as.factor(prefecture)4    4.286e-01  5.611e-02   7.639 2.18e-14 ***
as.factor(qt)2:as.factor(hpbc)2     -8.828e-01  2.964e-02 -29.779  < 2e-16 ***
as.factor(qt)3:as.factor(hpbc)2      7.285e-01  3.109e-02  23.437  < 2e-16 ***
as.factor(qt)4:as.factor(hpbc)2      7.500e-01  2.943e-02  25.481  < 2e-16 ***
as.factor(prefecture)3:as.factor(hpbc)2 -8.481e-01  2.108e-02 -40.235  < 2e-16 ***
as.factor(prefecture)4:as.factor(hpbc)2         NA         NA      NA       NA
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1039281  on 89481  degrees of freedom
Residual deviance:  536118  on 89423  degrees of freedom
AIC: 602352

Number of Fisher Scoring iterations: 6


Analysis of Deviance Table (Type II tests)

Response: cbind(blshrk, osharks)
                                     LR Chisq Df Pr(>Chisq)
pcr                                     43044  1  < 2.2e-16 ***
poly(lon, 2)                             1972  2  < 2.2e-16 ***
poly(lat, 2)                             2422  2  < 2.2e-16 ***
as.factor(qt)                             636  3  < 2.2e-16 ***
as.factor(prefecture)                   41565  2  < 2.2e-16 ***
as.factor(hpbc)                         31347  1  < 2.2e-16 ***
pcr:poly(lon, 2)                         1374  2  < 2.2e-16 ***
pcr:poly(lat, 2)                         8051  2  < 2.2e-16 ***
pcr:as.factor(qt)                        1346  3  < 2.2e-16 ***
pcr:as.factor(prefecture)                4540  2  < 2.2e-16 ***
poly(lon, 2):poly(lat, 2)                9230  4  < 2.2e-16 ***
poly(lon, 2):as.factor(qt)               1121  6  < 2.2e-16 ***
poly(lon, 2):as.factor(prefecture)       2403  4  < 2.2e-16 ***
poly(lon, 2):as.factor(hpbc)             1755  2  < 2.2e-16 ***
poly(lat, 2):as.factor(qt)               4372  6  < 2.2e-16 ***
poly(lat, 2):as.factor(prefecture)      14291  4  < 2.2e-16 ***
poly(lat, 2):as.factor(hpbc)             8092  2  < 2.2e-16 ***
as.factor(qt):as.factor(prefecture)      3553  6  < 2.2e-16 ***
as.factor(qt):as.factor(hpbc)            4196  3  < 2.2e-16 ***
as.factor(prefecture):as.factor(hpbc)    1668  1  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

>



Enyo Simple model
Call:
glm(formula = cbind(blshrk, osharks) ~ pcr, family = binomial,
 data = edata)

Deviance Residuals:
```
   Min      1Q  Median      3Q     Max
-62.93    0.00    0.00    0.00   34.93
```

Coefficients:
```
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -3.93729    0.01510  -260.7   <2e-16 ***
pcr          6.10215    0.01603   380.7   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

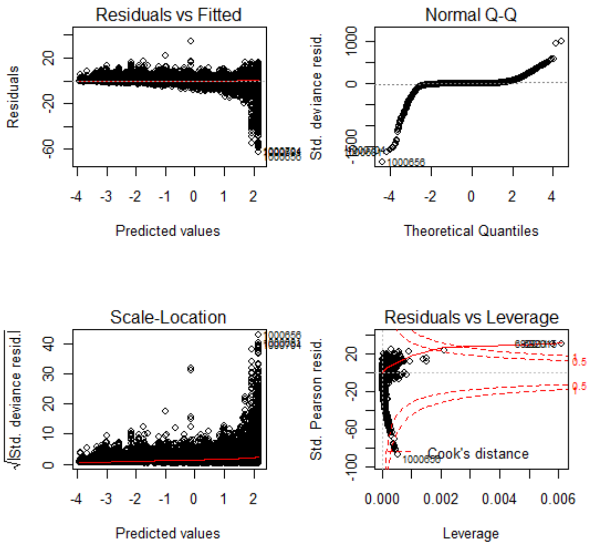
(Dispersion parameter for binomial family taken to be 1)

```
    Null deviance: 1039281  on 89481  degrees of freedom
Residual deviance:  843441  on 89480  degrees of freedom
AIC: 909561
```

Number of Fisher Scoring iterations: 4

Analysis of Deviance Table (Type II tests)

Response: cbind(blshrk, osharks)
```
    LR Chisq Df Pr(>Chisq)
pcr   195841  1  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. Pearson resid.
Cook's distance
Leverage