Comparison of CPUEs of Blue Shark Reported by Logbook of Japanese Commercial Longliners with Japanese Research and Training Longline Data

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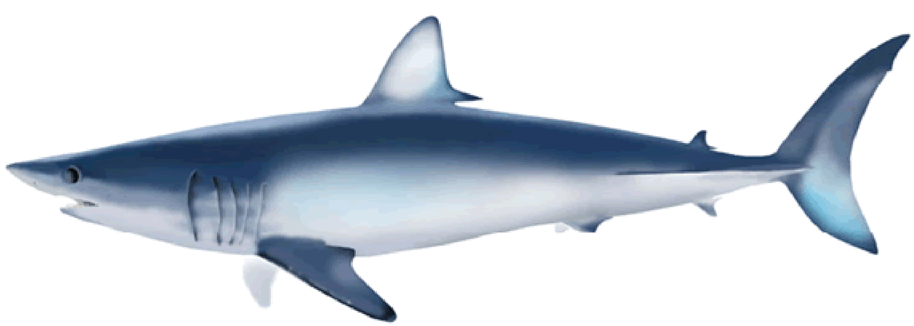

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Abstract

Some portion of blue shark (*Prionace glauca*) catch by Japanese commercial longliners is known to be often unreported. This paper is our attempt to compare blue shark catch recorded in logbooks from Japanese commercial longliners with "reference" catch.

The "reference" catch based on catch and effort data recorded by research and/or "fisheries high school" training vessels for which all of their catch were observed and reported. For commercial longline fishery, the same catch and effort data as in Hiraoka et al. (2012) were used except that subsets of the data corresponding to the spatiotemporal coverage overlapped with and the same values of hooks per basket as "reference" data were extracted. To compare differences between blue shark catch of Japanese longline fishery and its "reference", the ratio of the two catch rates was calculated. The ratio was computed for each of three combinations of vessel types ("Kinkai" or "Enyo") and longline set categories (deep or shallow set) as defined in Hiraoka et al. (2012), except for "Kinkai"-deep set combination. All catch rates were standardized by GLM before calculating the ratios.

The ratios varied year to year for analysis periods. There was no particular systematic pattern (neither increasing nor decreasing) observed in any of year trends of the ratios for three vessel type/set category combinations. For "Kinkai"- and "Enyo"-shallow set fleets, the ratios fluctuated between 0.6 and 1.5. There were several reasons which caused higher catch rates of the research vessels and consequently produced the ratios less than 1.0. Considering these reasons, it may be valid to assume that both "Kinkai"- and "Enyo"-shallow set fleets have properly reported their blue shark catch. In contrast, the ratios for "Enyo"-deep set fleet fluctuated between 0.04 and 0.10, suggesting that an unignorable portion of blue shark catch by this fleet has been unreported.

It was difficult to draw a decisive conclusion on the unreported issue because available information was truly limited. Given large uncertainties about the unreported portion in total blue shark catch, final conclusion should be synthetically drawn from multiple results from this paper and other analyses.

Introduction

Japanese commercial longline vessels, whether targeting or non-targeting, catch a fair amount of blue shark (*Prionace glauca*) in the North Pacific Ocean. Some portion of the catch is known to be often unreported in logbooks, due to limitation of the capacity of fish hold and their management strategy. Without doubt characterization of total catch is the mandatory first step in a whole stock assessment process. Thus, it is worthwhile to investigate the unreported portion in total blue shark catch by some way or other.

This paper reports our attempt to compare blue shark catch recorded in logbooks from Japanese commercial longliners with "reference" catch data. The comparison was done by examining the ratio of reported catch by commercial vessels to "reference" catch. The "reference" catch based on catch and effort data recorded by research and/or "fisheries high school" training vessels for which all of their catch were observed and reported. Estimation of blue shark catch for various Japanese longline fleets conducted in Hiraoka et al. (2012) utilized some of the results from this paper for adjustment of catch.

Methods and Data used

To compare and examine differences between blue shark catch of Japanese longline fishery and "reference" catch data, the ratio of the two catch rates was calculated as below:

$$\mu.\text{ratio}_{\text{year i}} = \frac{\text{Standardized catch per 1000 hooks for commercial fleet in year i}}{\text{Standardized "reference" catch per 1000 hooks in year i}}$$

The ratio was computed for each of three combinations of vessel types ("Kinkai" or "Enyo") and longline set categories (deep or shallow set) as defined in Hiraoka et al. (2012), except for "Kinkai"-deep set combination (because there was no comparable "reference" data available for this combination). "Kinkai" and "Enyo" vessels are defined by the size of vessel ("Kinkai" is smaller than 121 ton and "Enyo" is larger than 120 ton). All "Kinkai" longliners unload their catch as fresh whereas the majority of "Enyo" longliners unload the catch as frozen, and thus their strategies of shark transport and unloading should be different from one another. All catch rates were standardized to obtain year trends before calculating the ratios (see below for standardization models). The 95% confidence interval (95%CI) of the ratio was estimated based on 1000 bootstrap resamples.

The "reference" catch rate based on catch and effort data for which all of the catch were observed and reported. There are two sources of such information available in the database of National Research Institute of Far Seas Fisheries (NRIFSF). One is the dataset compiled from logsheet records of research vessels belonging to, or chartered to, national or prefectural fisheries research institutes (national institutes or local laboratories), and from logbook records submitted by vocational training vessels attached to "fisheries high schools" in Japan. As these training and research vessels target tunas with deep sets and catch blue shark mainly as by-catch, these catch and effort data are considered suitable for "reference" of commercial fleet catch ("Enyo"-deep set fleet catch), not-targeting blue shark (Hiraoka et al. 2012). We will call these data "JTR data" hereafter (Table 1).

The other source of information is the dataset compiled from logsheet records of research vessels chartered to NRIFSF. As these research vessels were originally commercial ones and especially chartered for conducting surveys of by-catch species, the catch and effort data of these vessels are considered appropriate for "reference" of commercial fleet catch ("Kinkai"-shallow set and "Enyo"-shallow set fleet catch), targeting primarily blue shark and swordfish (Hiraoka et al. 2012). We will call these data "TK data" hereafter (Table 1). Both JTR and TK data were compiled in set-by-set, 1x1 degree square resolution.

Table 1. Vessel type/set category combinations and corresponding "reference" catch data used in analyses.

Targeting blue shark?	Targeting		Not-targeting
Vessel type / set category combination	"Kinkai"-shallow	"Enyo"-shallow	"Enyo"-deep
"Reference" catch data used	"TK data"		"JTR data"

The same catch and effort data as in Hiraoka et al. (2012) were used for commercial longline fishery, except that some extractions were done and the subsets of the data were used in our analyses. To calculate the ratio of commercial catch to "reference" and examine the ratio for comparing the difference of the two, commercial catch data corresponding to the spatiotemporal coverage overlapped with and the same values of hooks per basket as "reference" data were extracted as follows:

(1) "Kinkai"-shallow and "Enyo"-shallow sets

Year range: 2000, 2002 - 2010
Month range: April - July
Spatial coverage: 25 deg N ≤ latitude < 40 deg N,

140 deg E ≤ longitude < 165 deg E
Hooks per basket: 4 hooks
Outlier removal: ≥ 400 catch per 1000 hooks

Data for year 2001 were not used because "reference" TK data for that year showed unrealistically high variations and were removed from analyses considering as outliers.

(2) "Enyo"-deep set

Year range: 1994 - 2006
Month range: January - December
Spatial coverage: 10 deg N ≤ latitude < 40 deg N,
120 deg W < longitude ≤ 180 deg
Hooks per basket: ≥ 7 hooks
Outlier removal: ≥ 100 catch per 1000 hooks

For "reference" JTR data, records describing sets in which < 500 hooks were used were removed because some operations may have been designed to test new gear and thus would use only a small number of hooks.

After the data extractions on the conditions above and other error record removals were done, resulting numbers of records for each dataset were as follows:

3 445 records for "Kinkai"-shallow set fleet data
649 records for "Enyo"-shallow set fleet data

74 938 records for "Enyo"-deep set fleet data

446 records for TK data
18 788 records for JTR data

Prior to GLM standardization of CPUE, close examinations of raw data were made, then variables to be included in statistical models, which appeared to influence CPUE changes, were listed and sets of candidate models were formulated. Final standardization models were selected using information theoretic criteria (AIC and BIC). All GLM standardizations assumed the negative binomial distribution and applied the logarithm link function. GLM analyses were done using R software (ver.2.12.2; R Development Core Team 2011). Summary outputs of the analyses from R were attached as Appendix. Final GLM standardization models selected for each fleet and "reference" were as follows:

(a) "Kinkai"-shallow set fleet

catch ~ year + month + lon5 + lat.aggr + year*month + year*lat.aggr + month*lon5 + month*lat.aggr + offset(log(hooks))

lon5: Longitudinal 5 degree categories
lat.aggr: Latitudinal < 35 degree N and ≥ 35 degree N categories.

(b) "Enyo"-shallow set fleet

catch ~ year + month + lon5 + lat.aggr + month*lon5 + month*lat.aggr + offset(log(hooks))

(c) "Enyo"-deep set fleet

catch ~ year + month + lon5 + area + month*area + offset(log(hooks))

area: Latitudinal < 20 degree N and ≥ 20 degree N categories.

(d) Research vessels chartered to NRIFSF ("TK data")

catch ~ year + month + lat.aggr + offset(log(hooks))

(e) Japanese training and research vessels ("JTR data")

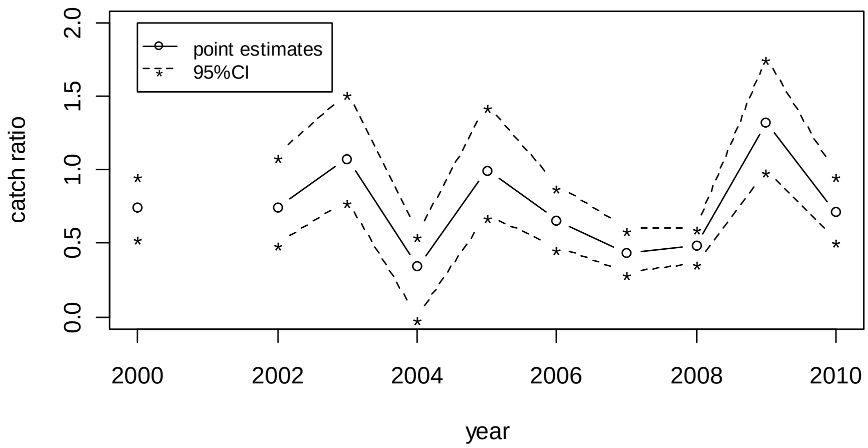
catch ~ year + trim + lon5 + area + trim*area + offset(log(hooks))

trim: Trimester categories (i.e., April-July, August-November and December-March)

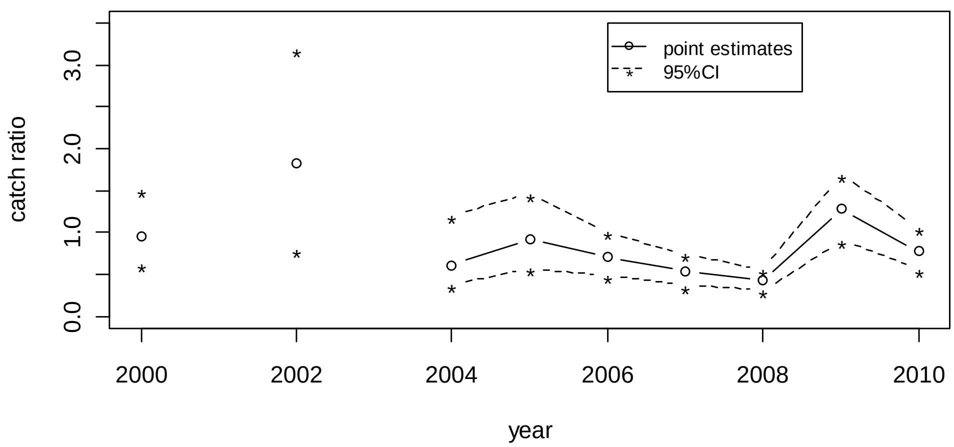
Results and Discussion

The ratios of reported catch of Japanese commercial longliners to its "reference" catch varied year to year (Fig. 1; values of the ratios were summarized in Table 2). The ratios for year 2001 for "Kinkai"- and "Enyo"-shallow set fleets could not be calculated because "reference" TK data for 2001 showed unrealistically high variations and were removed from analyses as outliers. Also, the ratio for 2003 for "Enyo"-shallow set fleet was not available because there were no data of "Enyo"-shallow set operations for 2003 within the spatiotemporal coverage overlapped with "reference" TK data. There was no particular systematic pattern (neither increasing nor decreasing) observed in any of ratio trends for three vessel type/set category combinations. Overall means throughout the analysis periods were 0.75, 0.89 and 0.07 for "Kinkai"-shallow, "Enyo"-shallow and "Enyo"-deep set fleets, respectively.

(a) "Kinkai"-shallow set fleet



(b) "Enyo"-shallow set fleet



(c) "Enyo"-deep set fleet

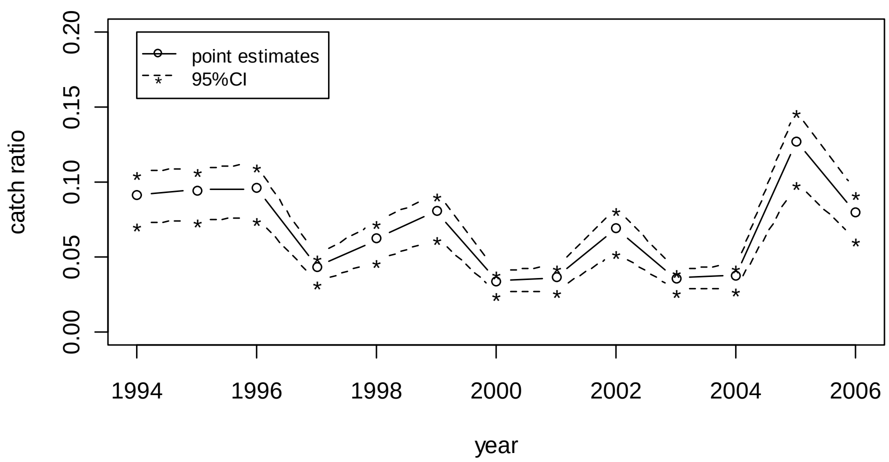


Figure 1. Ratios of blue shark catch rate reported by Japanese commercial longline fleets to "reference" catch rate ($\mu.\text{ratio}_{\text{year } i}$).

Table 2. Point estimates and 95% confidence intervals of the ratios of blue shark catch rate reported by Japanese commercial longline fleets to "reference" catch rate ($\mu.ratio_{year\ i}$).

(a) "Kinkai"-shallow set fleet

Year	μ.ratio		
	Point estimate	Lower 95% CI	Upper 95% CI
2000	0.75	0.54	0.97
2001	NA	NA	NA
2002	0.75	0.51	1.11
2003	1.08	0.79	1.53
2004	0.34	0.00	0.57
2005	1.00	0.70	1.45
2006	0.66	0.48	0.90
2007	0.43	0.30	0.61
2008	0.48	0.37	0.61
2009	1.33	1.00	1.77
2010	0.71	0.53	0.97

(b) "Enyo"-shallow set fleet

Year	μ.ratio		
	Point estimate	Lower 95% CI	Upper 95% CI
2000	0.95	0.61	1.52
2001	NA	NA	NA
2002	1.83	0.80	NA
2003	NA	NA	1.53
2004	0.61	0.37	1.21
2005	0.92	0.57	1.47
2006	0.71	0.48	1.00
2007	0.53	0.37	0.74
2008	0.42	0.31	0.55
2009	1.28	0.90	1.69
2010	0.78	0.56	1.06

(c) "Enyo"-deep set fleet

Year	μ.ratio		
	Point estimate	Lower 95% CI	Upper 95% CI
1994	0.09	0.07	0.11
1995	0.09	0.07	0.11
1996	0.10	0.08	0.11
1997	0.04	0.03	0.05
1998	0.06	0.05	0.07
1999	0.08	0.06	0.09
2000	0.03	0.03	0.04
2001	0.04	0.03	0.04
2002	0.07	0.05	0.08
2003	0.04	0.03	0.04
2004	0.04	0.03	0.04
2005	0.13	0.10	0.15
2006	0.08	0.06	0.09

For "Kinkai"- and "Enyo"-shallow set fleets, the ratios of commercial catch rate to "reference" mostly fluctuated between 0.6 and 1.5 (Fig. 1a and b, Table 2a and b). In some years, differences between the two catch rates were over 100%, suggesting that these shallow set fleets may have properly reported their blue shark catch in logbooks. In some other years, however, the ratios were less than 1.0. There would be several reasons considered why these differences between the catch rates occurred. One is that research vessels chartered to NRIFSF were originally commercial vessels, and thus fishing ability of the research vessels did not differ from other commercial longliners. The other reason is that, for survey purposes, the research vessels were especially provided with detailed information about fishing grounds from other commercial longliners as privilege. In addition, the research vessels were allowed to search fishing grounds for a couple of days until positions to be able to expect good catch of blue shark were found (which are not usually allowed during ordinary commercial operations). These facts may have caused higher catch rates of the research vessels and consequently produced the ratios less than 1.0. Given consideration above, it may be reasonable to assume that both "Kinkai"- and "Enyo"-shallow set fleets have properly reported their catch, and therefore, all data obtained from these shallow set fleets can be used for catch and CPUE index estimation.

For "Enyo"-deep set fleet, the ratios of commercial catch rate to "reference" fluctuated between 0.04 and 0.10 for the most part of the analysis period (Fig. 1c, Table 2c). This suggests that a considerable portion of blue shark catch by "Enyo"-deep fleet has been unreported in logbooks. Therefore, some adjustment is necessary when estimating overall catch for this fleet, and furthermore catch data from this fleet should not be used for CPUE index estimation.

The majority of "reference" catch data of Enyo-deep set fleet (JTR data) were obtained from fishery high school training vessels. Many of these vessels use wire leaders as a safety measure to avoid serious accidents of students (e.g., eye injuries, severe skin welt) caused by sudden snapping of a hook line by teeth of struggling shark during fish retrieving. A fine monofilament nylon hook line, suited to catch tunas though, is quite often be cut off by sharp teeth of pelagic sharks during their retrieving, and the wire leader is one of popular hook lines used for shark directed longline operation. In contrast to the training vessels, all commercial deep longliners adopt the fine monofilament nylon hook line to increase the catch rate of tunas. Although there is no information available about actual differences in catch abilities between these two types of hook line, the retention ratio of blue shark catch estimated in this paper should underestimate actual retention rate of Japanese commercial deep longliners.

We examined differences between catch rates of Japanese commercial longliners and the corresponding "reference" catch rates basing on the best available data. However, it is difficult to draw a decisive conclusion from these data because information is truly limited. Given large uncertainties about the unreported portion in total blue shark catch, a final conclusion on this issue should be synthetically drawn from multiple results from this paper and other analyses (e.g., Hiraoka et al. 2012, Yokawa and Kimoto 2012).

References

Hiraoka, Y., M. Kanaiwa and K.Yokawa. 2012. Estimation of total blue shark catches including releases and discards Japanese longline fisheries during 1975 and 2010 in the North Pacific. Document submitted to the ISC Shark Working Group Workshop, 28 May-4 June, 2012. ISC/12/SHARKWG-1/xx.

R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Yokawa, K. and A. Kimoto. 2012. Blue shark catch of Japanese surface longliners registered in Kesennuma fishing port. Document submitted to the ISC Shark Working Group Workshop, 28 May-4 June, 2012. ISC/12/SHARKWG-1/xx.

Appendix:

Summary outputs of GLM analyses from R

(a) "Kinkai"-shallow set fleet

```
Call:
glm.nb(formula = blshrk ~ as.factor(year2) + as.factor(month) +
    as.factor(lon5) + as.factor(lat5aggr) + as.factor(year2):as.factor(month) +
    as.factor(year2):as.factor(lat5aggr) + as.factor(month):as.factor(lon5) +
    as.factor(month):as.factor(lat5aggr) + offset(log(hooks)),
    data = dd.com.0010, init.theta = 1.276431766, link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.8010  -0.8653  -0.2372   0.3412   4.0815

Coefficients:
                                     Estimate Std. Error z value Pr(>|z|)
(Intercept)                         -4.072073   0.105242 -38.692  < 2e-16 ***
as.factor(year2)2                   -0.151280   0.123385  -1.226 0.220167
as.factor(year2)3                   -0.388540   0.145016  -2.679 0.007378 **
as.factor(year2)4                   -0.097555   0.183734  -0.531 0.595449
as.factor(year2)5                   -0.783991   0.216851  -3.615 0.000300 ***
as.factor(year2)6                    0.210321   0.128223   1.640 0.100949
as.factor(year2)7                    0.155437   0.157891   0.984 0.324889
as.factor(year2)8                   -0.378820   0.143970  -2.631 0.008507 **
as.factor(year2)9                   -0.432927   0.130905  -3.307 0.000942 ***
as.factor(year2)10                   0.884932   0.135490   6.531 6.52e-11 ***
as.factor(year2)11                   0.182469   0.158371   1.152 0.249256
as.factor(month)5                   -0.273732   0.156274  -1.752 0.079840 .
as.factor(month)6                    0.283300   0.148823   1.904 0.056961 .
as.factor(month)7                    0.600823   0.209174   2.872 0.004074 **
as.factor(lon5)145                   0.324696   0.092505   3.510 0.000448 ***
as.factor(lon5)150                   0.324695   0.106034   3.062 0.002197 **
as.factor(lon5)155                   0.195845   0.115157   1.701 0.089003 .
as.factor(lon5)160                  -0.387745   0.094428  -4.106 4.02e-05 ***
as.factor(lat5aggr)35                1.302200   0.134359   9.692  < 2e-16 ***
as.factor(year2)2:as.factor(month)5   0.428153   0.178326   2.401 0.016352 *
as.factor(year2)3:as.factor(month)5  -0.053522   0.199251  -0.269 0.788223
as.factor(year2)4:as.factor(month)5   0.444136   0.253518   1.752 0.079792 .
as.factor(year2)5:as.factor(month)5  -1.145741   0.408495  -2.805 0.005035 **
as.factor(year2)6:as.factor(month)5   0.766793   0.194824   3.936 8.29e-05 ***
as.factor(year2)7:as.factor(month)5  -0.185296   0.242615  -0.764 0.445019
as.factor(year2)8:as.factor(month)5  -0.310921   0.215118  -1.445 0.148360
as.factor(year2)9:as.factor(month)5   0.925842   0.202357   4.575 4.76e-06 ***
as.factor(year2)10:as.factor(month)5  0.268364   0.185719   1.445 0.148457
as.factor(year2)11:as.factor(month)5  0.352421   0.228983   1.539 0.123787
as.factor(year2)2:as.factor(month)6   0.588389   0.188695   3.118 0.001820 **
as.factor(year2)3:as.factor(month)6  -0.613403   0.244371  -2.510 0.012069 *
as.factor(year2)4:as.factor(month)6   0.388258   0.287722   1.349 0.177202
as.factor(year2)5:as.factor(month)6  -0.428530   0.498729  -0.859 0.390205
as.factor(year2)6:as.factor(month)6   0.836191   0.257976   3.241 0.001190 **
as.factor(year2)7:as.factor(month)6  -0.322885   0.302915  -1.066 0.286457
as.factor(year2)8:as.factor(month)6   0.542554   0.220412   2.462 0.013834 *
as.factor(year2)9:as.factor(month)6   0.576195   0.179237   3.215 0.001306 **
as.factor(year2)10:as.factor(month)6  0.346247   0.201917   1.715 0.086382 .
as.factor(year2)11:as.factor(month)6 -0.061322   0.240844  -0.255 0.799022
as.factor(year2)2:as.factor(month)7   0.318668   0.220952   1.442 0.149232
as.factor(year2)3:as.factor(month)7   0.224457   0.294817   0.761 0.446452
as.factor(year2)4:as.factor(month)7   1.001295   0.290034   3.452 0.000556 ***
```

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as.factor(year2)5:as.factor(month)7        1.683232   0.569893   2.954 0.003141 **
as.factor(year2)6:as.factor(month)7        1.528689   0.326896   4.676 2.92e-06 ***
as.factor(year2)7:as.factor(month)7       -0.385719   0.332981  -1.158 0.246707
as.factor(year2)8:as.factor(month)7        0.718391   0.280605   2.560 0.010463 *
as.factor(year2)9:as.factor(month)7        0.955370   0.240536   3.972 7.13e-05 ***
as.factor(year2)10:as.factor(month)7       0.377055   0.258150   1.461 0.144123
as.factor(year2)11:as.factor(month)7      -0.283651   0.287853  -0.985 0.324426
as.factor(year2)2:as.factor(lat5aggr)35  -0.046103   0.144661  -0.319 0.749956
as.factor(year2)3:as.factor(lat5aggr)35   0.854016   0.182727   4.674 2.96e-06 ***
as.factor(year2)4:as.factor(lat5aggr)35  -0.192543   0.204465  -0.942 0.346351
as.factor(year2)5:as.factor(lat5aggr)35   0.119045   0.405514   0.294 0.769090
as.factor(year2)6:as.factor(lat5aggr)35  -0.809375   0.206840  -3.913 9.11e-05 ***
as.factor(year2)7:as.factor(lat5aggr)35   0.434792   0.240953   1.804 0.071158 .
as.factor(year2)8:as.factor(lat5aggr)35  -0.173496   0.187849  -0.924 0.355698
as.factor(year2)9:as.factor(lat5aggr)35  -0.441985   0.152093  -2.906 0.003661 **
as.factor(year2)10:as.factor(lat5aggr)35 -0.964418   0.161750  -5.962 2.49e-09 ***
as.factor(year2)11:as.factor(lat5aggr)35 -0.002534   0.203643  -0.012 0.990073
as.factor(month)5:as.factor(lon5)145       0.226065   0.138587   1.631 0.102846
as.factor(month)6:as.factor(lon5)145      -0.646348   0.130022  -4.971 6.66e-07 ***
as.factor(month)7:as.factor(lon5)145      -1.062870   0.162355  -6.547 5.89e-11 ***
as.factor(month)5:as.factor(lon5)150       0.377389   0.155277   2.430 0.015081 *
as.factor(month)6:as.factor(lon5)150      -0.303492   0.152674  -1.988 0.046829 *
as.factor(month)7:as.factor(lon5)150      -1.038072   0.194140  -5.347 8.94e-08 ***
as.factor(month)5:as.factor(lon5)155       0.024497   0.165490   0.148 0.882321
as.factor(month)6:as.factor(lon5)155      -0.144789   0.159751  -0.906 0.364755
as.factor(month)7:as.factor(lon5)155      -0.578852   0.170781  -3.389 0.000700 ***
as.factor(month)5:as.factor(lon5)160       0.772598   0.135175   5.716 1.09e-08 ***
as.factor(month)6:as.factor(lon5)160       0.794815   0.131465   6.046 1.49e-09 ***
as.factor(month)7:as.factor(lon5)160       0.201833   0.142943   1.412 0.157955
as.factor(month)5:as.factor(lat5aggr)35  -0.441922   0.111814  -3.952 7.74e-05 ***
as.factor(month)6:as.factor(lat5aggr)35  -0.706316   0.126157  -5.599 2.16e-08 ***
as.factor(month)7:as.factor(lat5aggr)35  -1.280807   0.170553  -7.510 5.92e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(1.2764) family taken to be 1)

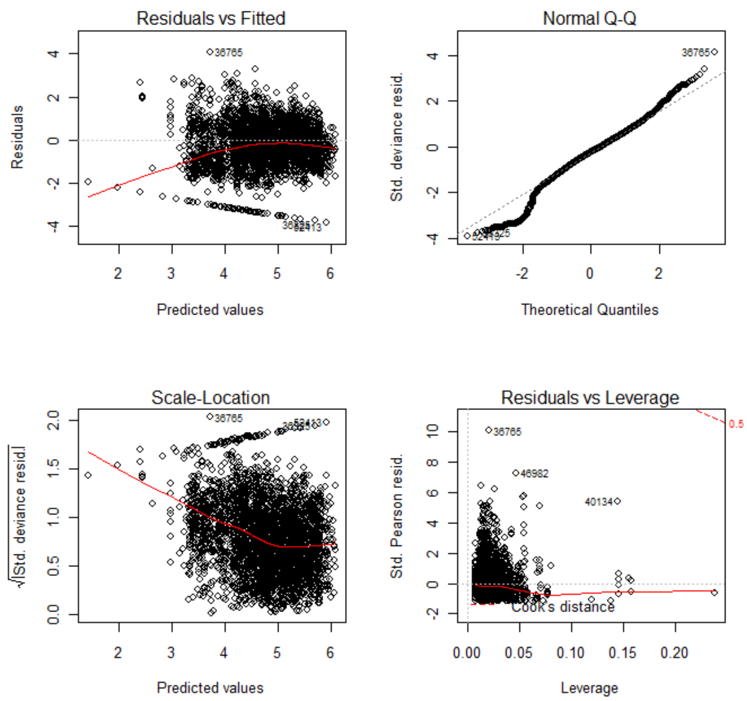
    Null deviance: 5566.6  on 3444  degrees of freedom
Residual deviance: 4051.0  on 3371  degrees of freedom
AIC: 39517

Number of Fisher Scoring iterations: 1

              Theta:  1.2764
          Std. Err.:  0.0302

 2 x log-likelihood:  -39366.6270

#AIC
[1] 39516.63
#BIC
[1] 39977.48
```



(b) "Enyo"-shallow set fleet

```
Call:
glm.nb(formula = blshrk ~ as.factor(year2) + as.factor(month) +
    as.factor(lon5) + as.factor(lat5aggr) + as.factor(month):as.factor(lon5) +
    as.factor(month):as.factor(lat5aggr) + offset(log(hooks)),
    data = dd.com.0010, init.theta = 2.212487245, link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.1472  -0.8824  -0.2380   0.4469   2.9774

Coefficients:
                                 Estimate Std. Error z value Pr(>|z|)
(Intercept)                      -3.19313    0.27051 -11.804  < 2e-16 ***
as.factor(year2)2                -0.10634    0.24733  -0.430 0.667242
as.factor(year2)3                 0.58717    0.31114   1.887 0.059139 .
as.factor(year2)5                -0.34808    0.32780  -1.062 0.288301
as.factor(year2)6                 0.27812    0.25993   1.070 0.284623
as.factor(year2)7                -0.00207    0.24810  -0.008 0.993344
as.factor(year2)8                -0.25997    0.24230  -1.073 0.283307
as.factor(year2)9                -0.40376    0.24469  -1.650 0.098924 .
as.factor(year2)10                0.38321    0.24236   1.581 0.113832
as.factor(year2)11                0.03395    0.23829   0.142 0.886700
as.factor(month)5                -0.39211    0.19820  -1.978 0.047893 *
as.factor(month)6                -0.32121    0.18825  -1.706 0.087958 .
as.factor(month)7                 0.23847    0.23775   1.003 0.315854
as.factor(lon5)145               -0.57234    0.18297  -3.128 0.001760 **
as.factor(lon5)150               -0.45907    0.20656  -2.222 0.026255 *
as.factor(lon5)155               -1.27647    0.21591  -5.912 3.38e-09 ***
as.factor(lon5)160               -2.13842    0.19640 -10.888  < 2e-16 ***
as.factor(lat5aggr)35             1.11096    0.13326   8.337  < 2e-16 ***
as.factor(month)5:as.factor(lon5)145    0.83566    0.24193   3.454 0.000552 ***
```

```
as.factor(month)6:as.factor(lon5)145      0.40502     0.21242    1.907 0.056558 .
as.factor(month)7:as.factor(lon5)145      0.46096     0.28836    1.599 0.109928
as.factor(month)5:as.factor(lon5)150      0.70815     0.26060    2.717 0.006580 **
as.factor(month)6:as.factor(lon5)150     -0.15945     0.33990   -0.469 0.638996
as.factor(month)7:as.factor(lon5)150      0.64238     0.71655    0.896 0.369997
as.factor(month)5:as.factor(lon5)155      0.92146     0.27243    3.382 0.000719 ***
as.factor(month)6:as.factor(lon5)155      1.27809     0.33668    3.796 0.000147 ***
as.factor(month)7:as.factor(lon5)155      0.84253     0.38942    2.164 0.030501 *
as.factor(month)5:as.factor(lon5)160      1.65318     0.25867    6.391 1.65e-10 ***
as.factor(month)6:as.factor(lon5)160      2.99114     0.25902   11.548  < 2e-16 ***
as.factor(month)7:as.factor(lon5)160      2.73532     0.40808    6.703 2.04e-11 ***
as.factor(month)5:as.factor(lat5aggr)35 -0.38672     0.18267   -2.117 0.034251 *
as.factor(month)6:as.factor(lat5aggr)35 -0.88511     0.18102   -4.890 1.01e-06 ***
as.factor(month)7:as.factor(lat5aggr)35 -1.40388     0.25441   -5.518 3.43e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(2.2125) family taken to be 1)

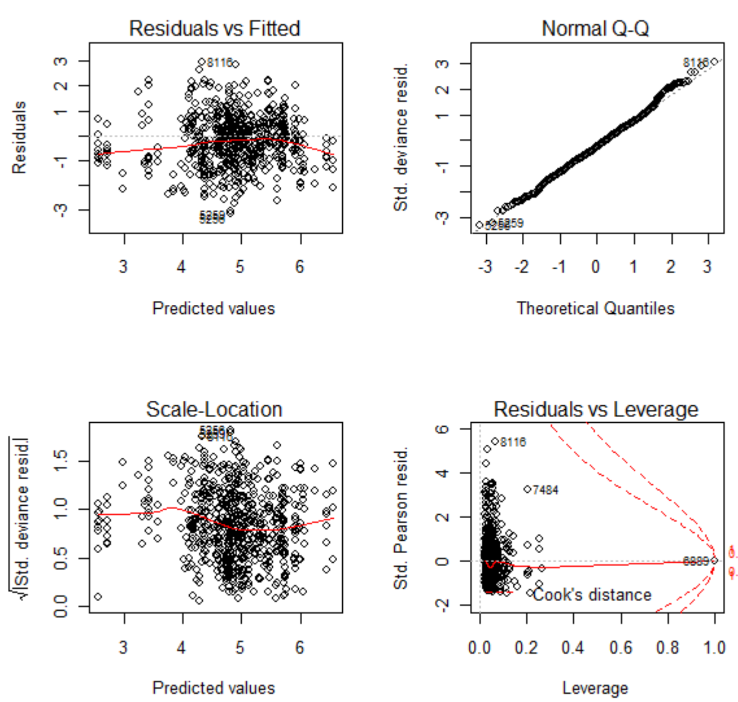
    Null deviance: 1253.58  on 648  degrees of freedom
Residual deviance:  696.35  on 616  degrees of freedom
AIC: 7505.4

Number of Fisher Scoring iterations: 1

              Theta:  2.212
          Std. Err.:  0.119

 2 x log-likelihood:  -7437.423

#AIC
[1] 7505.423
#BIC
[1] 7657.587
```



(c) "Enyo"-deep set fleet

```
Call:
glm.nb(formula = blshrk ~ as.factor(year2) + as.factor(month) +
    as.factor(lon5) + as.factor(area) + as.factor(month):as.factor(area) +
    offset(log(hooks)), data = dd.com9406, init.theta = 0.06864965571,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7813  -0.6034  -0.5470  -0.4699   4.5713

Coefficients:
                                 Estimate Std. Error z value Pr(>|z|)
(Intercept)                     -6.913701   0.116881 -59.152  < 2e-16 ***
as.factor(year2)2                0.008544   0.059863   0.143 0.886507
as.factor(year2)3                0.096850   0.068737   1.409 0.158837
as.factor(year2)4               -0.628981   0.074618  -8.429  < 2e-16 ***
as.factor(year2)5               -0.337971   0.076010  -4.446 8.73e-06 ***
as.factor(year2)6               -0.027141   0.064657  -0.420 0.674652
as.factor(year2)7               -0.934595   0.080003 -11.682  < 2e-16 ***
as.factor(year2)8               -1.099433   0.085081 -12.922  < 2e-16 ***
as.factor(year2)9               -0.373294   0.081854  -4.560 5.10e-06 ***
as.factor(year2)10              -0.869911   0.070336 -12.368  < 2e-16 ***
as.factor(year2)11              -0.964432   0.086008 -11.213  < 2e-16 ***
as.factor(year2)12              -0.083793   0.069955  -1.198 0.230993
as.factor(year2)13              -0.718487   0.068631 -10.469  < 2e-16 ***
as.factor(month)2               -0.039323   0.082590  -0.476 0.633985
as.factor(month)3               -0.190831   0.092184  -2.070 0.038442 *
as.factor(month)4                0.200593   0.104741   1.915 0.055476 .
as.factor(month)5                0.413389   0.090846   4.550 5.35e-06 ***
as.factor(month)6                0.710713   0.094723   7.503 6.24e-14 ***
as.factor(month)7                0.825280   0.135531   6.089 1.13e-09 ***
as.factor(month)8               -1.247655   0.334159  -3.734 0.000189 ***
as.factor(month)9                0.773990   0.214898   3.602 0.000316 ***
as.factor(month)10               0.232741   0.210816   1.104 0.269593
as.factor(month)11               0.013758   0.138726   0.099 0.920999
as.factor(month)12              -0.006036   0.111249  -0.054 0.956734
as.factor(lon5)185              -0.220818   0.112864  -1.957 0.050406 .
as.factor(lon5)190              -0.548567   0.106502  -5.151 2.59e-07 ***
as.factor(lon5)195              -0.736891   0.101353  -7.271 3.58e-13 ***
as.factor(lon5)200              -0.884584   0.101171  -8.743  < 2e-16 ***
as.factor(lon5)205              -0.923772   0.108355  -8.525  < 2e-16 ***
as.factor(lon5)210              -1.271027   0.105909 -12.001  < 2e-16 ***
as.factor(lon5)215              -1.464108   0.102994 -14.215  < 2e-16 ***
as.factor(lon5)220              -1.631265   0.102465 -15.920  < 2e-16 ***
as.factor(lon5)225              -1.497979   0.108709 -13.780  < 2e-16 ***
as.factor(lon5)230              -1.908930   0.123782 -15.422  < 2e-16 ***
as.factor(lon5)235              -1.795290   0.407791  -4.402 1.07e-05 ***
as.factor(area)2                 0.035372   0.080734   0.438 0.661296
as.factor(month)2:as.factor(area)2   0.165245   0.110453   1.496 0.134636
as.factor(month)3:as.factor(area)2   0.379061   0.170266   2.226 0.025995 *
as.factor(month)4:as.factor(area)2  -0.829498   0.910102  -0.911 0.362067
as.factor(month)5:as.factor(area)2  -0.132098   0.264593  -0.499 0.617604
as.factor(month)6:as.factor(area)2  -0.936523   0.250362  -3.741 0.000184 ***
as.factor(month)7:as.factor(area)2  -0.926194   0.190362  -4.865 1.14e-06 ***
as.factor(month)8:as.factor(area)2   1.405213   0.348679   4.030 5.58e-05 ***
as.factor(month)9:as.factor(area)2  -0.703720   0.231201  -3.044 0.002336 **
as.factor(month)10:as.factor(area)2 -0.437801   0.220864  -1.982 0.047455 *
as.factor(month)11:as.factor(area)2 -0.368495   0.152183  -2.421 0.015461 *
as.factor(month)12:as.factor(area)2 -0.312970   0.127065  -2.463 0.013775 *
---
```

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

(Dispersion parameter for Negative Binomial(0.0686) family taken to be 1)

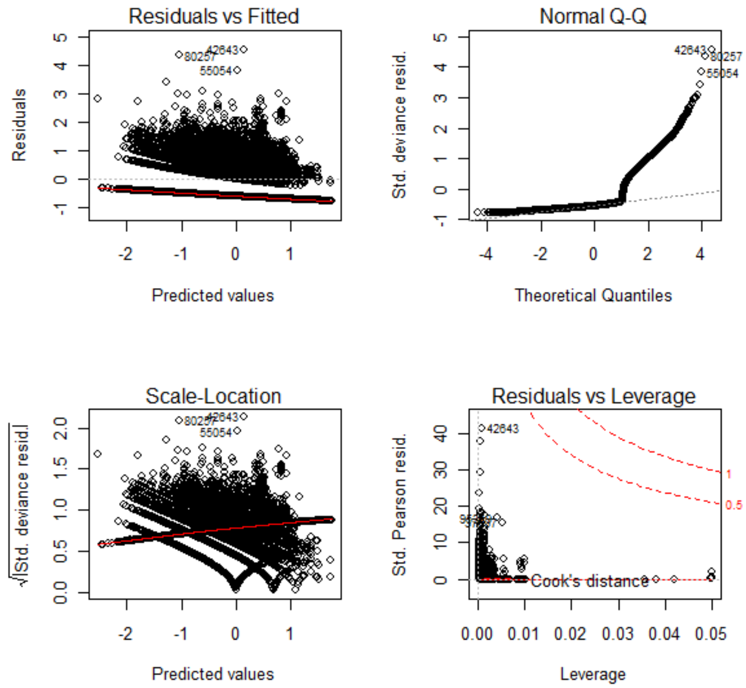
    Null deviance: 28429  on 74937  degrees of freedom
Residual deviance: 26401  on 74891  degrees of freedom
AIC: 117392

Number of Fisher Scoring iterations: 1

              Theta:  0.068650 
          Std. Err.:  0.000858 

 2 x log-likelihood:  -117295.625000 

#AIC
[1] 117391.6
#BIC
[1] 117834.4
```



(d) Research vessels chartered to NRIFSF ("TK data")

```
Call:
glm.nb(formula = blshrk ~ as.factor(year2) + as.factor(month) + 
    as.factor(lat5aggr) + offset(log(hooks)), data = dd.tk.0010, 
    init.theta = 1.350161157, link = log)

Deviance Residuals: 
    Min       1Q   Median       3Q      Max  
-3.3788  -0.8931  -0.3173   0.3157   3.9248  

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)    
(Intercept)          -3.75308    0.20227 -18.555  < 2e-16 ***
```

```
as.factor(year2)3     -0.07503    0.21331  -0.352 0.725024
as.factor(year2)4     -0.10135    0.20124  -0.504 0.614527
as.factor(year2)5      0.08684    0.20273   0.428 0.668413
as.factor(year2)6      0.30028    0.21865   1.373 0.169644
as.factor(year2)7      0.27838    0.19858   1.402 0.160962
as.factor(year2)8      0.31900    0.19544   1.632 0.102637
as.factor(year2)9      0.39968    0.20136   1.985 0.047157 *
as.factor(year2)10     0.07643    0.20165   0.379 0.704678
as.factor(year2)11     0.23090    0.20705   1.115 0.264754
as.factor(month)5      0.57535    0.16826   3.419 0.000627 ***
as.factor(month)6      0.17925    0.16697   1.073 0.283050
as.factor(month)7      0.37682    0.20308   1.855 0.063529 .
as.factor(lat5aggr)35  0.42448    0.09083   4.673 2.96e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(1.3502) family taken to be 1)

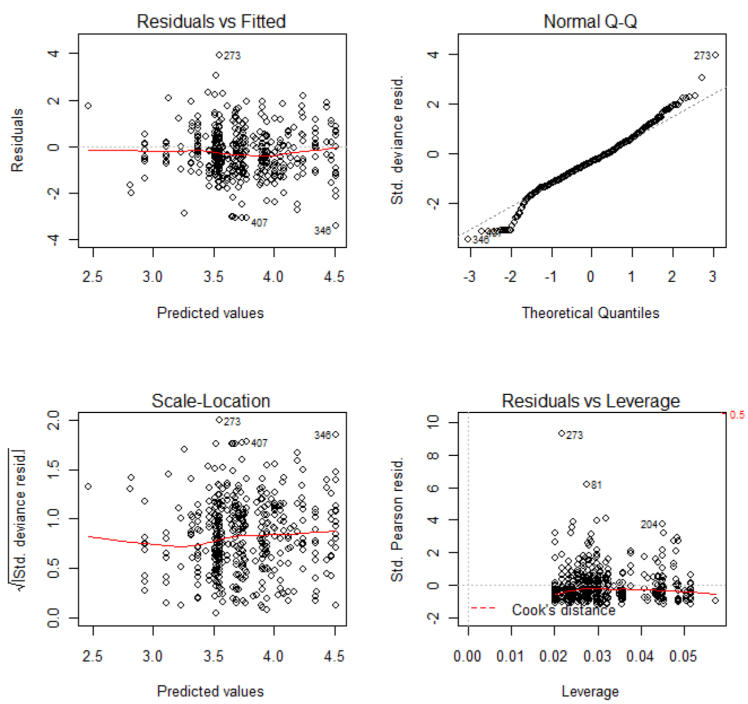
    Null deviance: 570.57  on 445  degrees of freedom
Residual deviance: 509.01  on 432  degrees of freedom
AIC: 4246

Number of Fisher Scoring iterations: 1

              Theta:  1.3502
          Std. Err.:  0.0889

 2 x log-likelihood:  -4216.0160

#AIC
[1] 4246.016
#BIC
[1] 4307.521
```



(e) Japanese training and research vessels ("JTR data")

```
Call:
glm.nb(formula = blshrk ~ as.factor(year2) + as.factor(trim) +
    as.factor(lon5) + as.factor(area) + as.factor(trim):as.factor(area) +
    offset(log(hooks)), data = dd.jtr9406, init.theta = 1.91903223,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.1014  -0.9437  -0.2847   0.3827   4.8730

Coefficients:
                                Estimate Std. Error  z value Pr(>|z|)
(Intercept)                     -4.90387    0.02552 -192.179  < 2e-16 ***
as.factor(year2)2               -0.02301    0.02737   -0.841 0.400423
as.factor(year2)3                0.04976    0.02789    1.784 0.074455 .
as.factor(year2)4                0.12062    0.02810    4.293 1.76e-05 ***
as.factor(year2)5                0.04929    0.02873    1.715 0.086264 .
as.factor(year2)6                0.10126    0.02808    3.606 0.000311 ***
as.factor(year2)7                0.05228    0.02821    1.853 0.063818 .
as.factor(year2)8               -0.18608    0.03052   -6.098 1.08e-09 ***
as.factor(year2)9               -0.08888    0.03110   -2.858 0.004260 **
as.factor(year2)10               0.06352    0.03056    2.079 0.037643 *
as.factor(year2)11              -0.07358    0.03013   -2.442 0.014591 *
as.factor(year2)12              -0.41084    0.03211  -12.796  < 2e-16 ***
as.factor(year2)13              -0.57941    0.03212  -18.038  < 2e-16 ***
as.factor(trim)2                 0.50244    0.03884   12.936  < 2e-16 ***
as.factor(trim)3                -0.05276    0.01536   -3.434 0.000595 ***
as.factor(lon5)185              -0.08187    0.02396   -3.417 0.000633 ***
as.factor(lon5)190              -0.44027    0.02544  -17.303  < 2e-16 ***
as.factor(lon5)195              -0.52230    0.02351  -22.220  < 2e-16 ***
as.factor(lon5)200              -0.58914    0.02117  -27.824  < 2e-16 ***
as.factor(lon5)205              -0.28411    0.02659  -10.686  < 2e-16 ***
as.factor(lon5)210              -0.16986    0.02885   -5.888 3.92e-09 ***
as.factor(lon5)215              -0.22232    0.04337   -5.126 2.96e-07 ***
as.factor(lon5)220              -0.38085    0.08604   -4.426 9.58e-06 ***
as.factor(lon5)225              -1.29134    0.20874   -6.186 6.16e-10 ***
as.factor(lon5)230              -0.94826    0.22683   -4.180 2.91e-05 ***
as.factor(area)2                -1.22322    0.38758   -3.156 0.001599 **
as.factor(trim)2:as.factor(area)2 -0.09697    0.38977   -0.249 0.803530
as.factor(trim)3:as.factor(area)2  1.67943    0.39289    4.275 1.92e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(1.919) family taken to be 1)

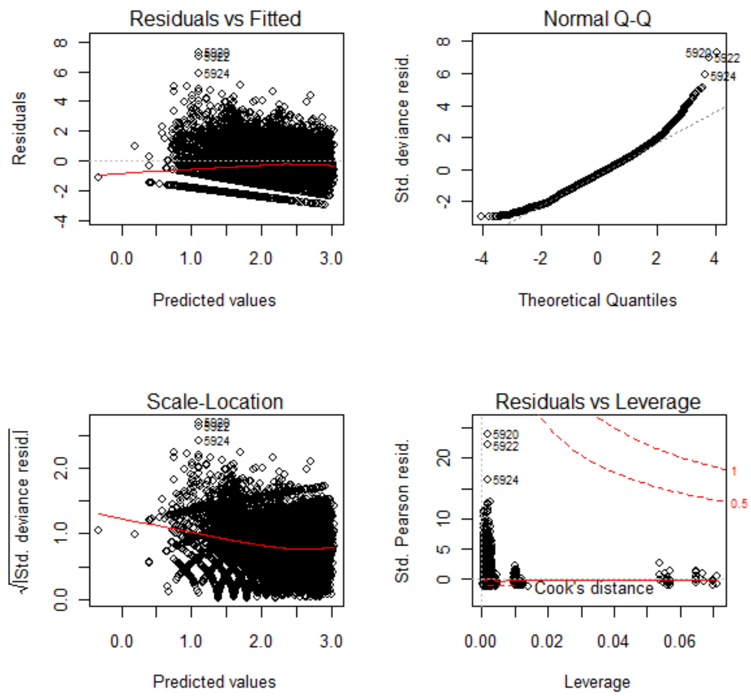
    Null deviance: 28595  on 18787  degrees of freedom
Residual deviance: 21005  on 18760  degrees of freedom
AIC: 115138

Number of Fisher Scoring iterations: 1

              Theta:  1.9190
          Std. Err.:  0.0255

 2 x log-likelihood:  -115079.6120

#AIC
[1] 115137.6
#BIC
[1] 115365
```


Residuals vs Fitted
Residuals
Predicted values
5920
5922
5924
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. Pearson resid.
Leverage
Cook's distance
1
0.5