ISC/13/SHARKWG-2/02

Summary of estimation process of abundance indices for blue shark in the North Pacific[1]

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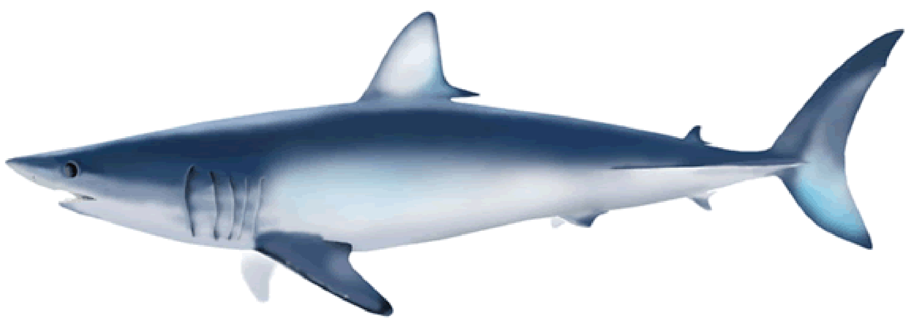

[1] Working document submitted to the ISC Shark Working Group Workshop, 16-24 April, 2013 National Research Institute of Far Seas Fisheries, Shizuoka, Japan. **Document not to be cited without author's permission.**

Abstract

In this working paper (WP), we summarized previous papers (Hiraoka et al., 2011; Hiraoka et al., 2012a, 2012b, 2012c, 2012d; Hiraoka et al., 2013) relating to the estimation of abundance indices of blue shark in the North Pacific because there were many discussions under the ISC shark working group before agreement on the final indicies. The last WP which described the accepted abundance indices for stock assessment cited many WPs of studies conducted before the final one. The objective of this WP is to provide the estimation process of the time series of abundance indices including data preparation and standardized CPUE. The detail of each analysis was described in the original papers.

The abundance indices of blue shark were estimated for the period between 1976 and 2010 using logbook data of shallow sets of Japanese longliners registered to Hokkaido & Tohoku prefectures, which actively target blue sharks. Because only species aggregated shark catch data is available for the period before 1994, blue shark specific catch data is estimated for this period by the species specific catch data after 1993. In this estimation, season-area specific ratio of blue shark catch to the total shark catch is assumed to be the same for the period before 1994 and after 1993. The standardizations of CPUE were conducted separately for the period before 1994 and after 1993 as the quality of data are different between two periods. Japanese shallow longline operations target both swordfish and blue shark using the same gear configuration (hooks per basket), thus the annual percentile of swordfish CPUE of each set is incorporated into the model of CPUE standardization as an explanatory variable. Although the annual trend of the estimated abundance index was decreasing during the period of 1980 to 1989, a continuous increasing trend was observed during the subsequent period except in 2007 and 2008.

Introduction

There are serious concerns about over exploitation of pelagic sharks by longline fisheries in the open ocean (Baum et al., 2003; Polovina et al., 2009). The blue shark (*Prionace glauca*) is known as the most abundant shark species and distributed worldwide in temperate and tropical waters (Nakano and Stevens, 2008). This species is characterized with high fecundity and fast growth relative to other pelagic sharks (Nakano, 1994; Smith et al., 2008) and thus a relatively higher tolerance against fishing pressure was indicated (Cortes, 2010). Although Kleiber et al. (2009) concluded the North Pacific blue shark population was stable and above their MSY biomass level, conservation concerns for this population have been raised more recently (Polovina et al., 2009; Clarke et al., 2011; Clarke et al., 2013).

An abundance index is one of the most fundamental elements needed for the stock assessment. Because abundance indices that are based on broad coverage, both spatially and temporally, are preferred for stock assessments, standardized CPUE of the Japanese longline fishery has been commonly utilized as an abundance index for tuna and tuna-like species (e.g. striped marlin in the Western and Central North Pacific; ISC, 2012). For shark species, Japanese logbook information has two serious problems. It only has data of species aggregated shark catch in the period between 1970 and 1993, and the reporting of discard and/or release sharks was not mandated. Nakano and Clarke (2006) reported that the species aggregated shark catch data in the logbook for trips with equal to/larger or than 80% of positive catch ratio of sharks can be assumed to accurately represent the catch of blue shark in the Atlantic in the period before 1994, and they successfully estimated an abundance index of blue shark for that period with this assumption. In the last stock assessment, the same method as Nakano and Clarke (2006) was applied to the logbook data of Japanese offshore and distant-water longliners operating in the

North Pacific to obtain the abundance index for the period between 1971 and 2002 (Kleiber et al., 2009). The filtering method addresses only the problem the positive catch rate. It is obvious that other factors should affect the blue shark catch such as oceanic environment and/or spatiotemporal pattern of effort. Moreover, different from the Atlantic, there are multiple types of longline fleets operating in the North Pacific such as distant-water and offshore tuna longliners with surface and deep sets (Yokawa 2005; Hiraoka et al., 2011). Thus, the way of exploitation and utilization of sharks could also be different from that in the Atlantic, and it should be more diverse (Taniuchi, 1990). By making allowances for the complexity of operation patterns of Japanese longliners in the North Pacific, an abundance index of blue shark was estimated using logbook data of Japanese offshore surface longliners registered to the Tohoku and Hokkaido regions which actively target blue shark. The species aggregated shark catch data in their logbooks for the period before 1994 was broken down to blue shark only catch by using their species specific shark catch data in the period after 1993. And also, their logbook data of retained catch of blue shark was extracted by higher filtering criterion than that in the Atlantic. In this study, to provide the abundance indices of blue shark in North Pacific, the new analytical approach was applied.

Materials and Methods

1. Data

Catch and effort data of Japanese longliners operating in the North Pacific (north of the equator) used in this analysis were compiled by the National Research Institute of Far Seas Fisheries for 1975-2010. Set by set data were used in the analysis, and they include information on catch number, amount of effort (number of hooks), the number of branch lines between floats (hooks per baskets: HPB) as a proxy for gear configuration, location of set by resolution of 1x1 degree, vessel category (Kinkai (offshore) and Enyo (distant-water)), and prefecture to which the longline boats were registered. Categories of Kinkai and Enyo are defined by the tonnage of vessel as below

- the Kinkai (offshore) fleet is defined as the vessels between 20 and 120 MT.
- the Enyo (distant water) fleet is the defined as the larger than 120 MT.

The gear configuration was defined as two categories, deep (HPB>6) and shallow (HPB<7), to have a simpler model structure. In general, the deep sets targeted tunas and the shallow sets targeted swordfish and blue shark. The data of sets for which HPB was smaller than 3 and larger than 21 were considered erroneous and removed from the analysis.

In the period before 1994, the logbook records only contain species aggregated catch of shark under the column of “sharks”. In the period after 1993, the logbook records contained 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. Therefore the time period was divided into "early" (1975-1993) and "late" (1994-2010).

Two types of reporting rate were estimated in the study. The first one was defined as the percentage of sets with any catch of sharks irrespective of species to the total sets per cruise. This reporting rate is the same one used by Nakano and Clarke (2006). This reporting rate was named PCR (positive catch ratio) in this study. The PCR was used as an explanatory variable to adjust the targeting for shark species in the model for the extraction of blue shark from the species aggregated catch of shark. The second one was RRZ (reporting rate by vessels) as defined by Clarke et al. (2011). This was applied to selected data sets of both "early" and "late" periods for estimation of abundance indices (Kinkai fleet with shallower setting registered in Hokkaido & Tohoku) to remove data of shallow sets with blue shark discard (i.e. blue shark catch higher than zero, but not reported). The level for this filter was set at 94.6% based on an analysis of RTV (Japanese research and training vessels) data and applied to standardize CPUE of blue shark caught by both RTV and commercial longline (Clarke et al., 2011).

2. Extraction of blue shark from species-combined catches of sharks in 1975-1993

Considering the vertical and horizontal distribution pattern and migratory behaviors of sharks, the ratio of blue shark to the species aggregated catch of sharks can vary by area, season, oceanographic conditions as well as target species of the set. In addition, Hiraoka et al. (2011) indicated the vessel register prefecture (as a proxy of the marketing for sharks) has an effect on the reporting ratio of blue shark in the catch of total shark species. Longliners registered to prefectures in the same area generally share the same market strategy of sharks, e.g., some of them actively unload sharks and others primarily unload tunas and billfishes only. Many longliners based in Kesennuma fishing port in Miyagi prefecture in Tohoku area (Fig. 1) actively unload sharks as there are a variety of shark processing facilities in Kesennuma city (Taniuchi 1990). Most longliners based on Kesennuma fishing port are registereed to Miyagi and surrounding prefectures. Species composition of unloaded catch of longliners is examined by prefectures. As mentioned above, longliners registered to prefectures around Miyagi (Tohoku and Hokkaido area) had a higher ratio of sharks (more than 40%) in the period between 1994 and 2010 and they are classified into a single group. The ratio of sharks of longliners registered to other prefectures was also investigated to classify them into the analytical group. The classification of Japanese prefectures group is shown in Fig. 1.

By considering these things, one statistical model was developed to explain the relationships between the ratio of blue shark and these factors mentioned above, and the relationships were estimated using the "late" data set 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 ratios of blue shark caught by Kinkai and Enyo were estimated separately as they have different unloading strategies 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 *SST, poly, season, prefecture, HPB* and *PCR* means sea surface temperature, orthogonal polynomials of longitude and latitude, 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 & Tohoku, 2: Oita and 3: others, for the model of distant-water longliners, 1: Hokkaido & Tohoku, 2: Kagoshima and 3: others, hooks per basket, and positive catch ratio in a cruise, respectively. In this model a binomial error distribution is assumed.

The selection of factors and their two way interactions which have significant effects was estimated by both direction step-wise methods using AIC as the model evaluation criteria. We recognized that adopted models using data after 1993 are the optimal models as the statistical diagnosis indicates that they fit the data best. Because no information of *SST* is available for the data before 1994, formulas without *SST* as a factor were the selected available models. To compare the results to the previous study conducted by Kleiber et al. (2009), two more models to estimate blue shark catch were examined. A model using only *PCR* as an explanatory variable is defined as the simple model and applied for extraction. The same equation as Kleiber et al., (2009) was also applied. Overall six models were estimated, i.e. Kinkai optimal model, Kinkai available model, Kinkai simple model, Enyo optimal model, Enyo available model and Enyo simple model. In addition, three kinds of estimated blue shark catches were compared by Kinki or Enyo, respectively. The calculations of Generalized Liner Model in this study were conducted using R 2.15.1.

3. CPUE standardization and estimation of abundance index

3-1. Process

Data were filtered by applying RRZ described by Clarke et al. (2011) which selected the data from individual vessels based on reporting rate being larger than 94.6%. i.e., the data of the vessels whose reporting ratio is lower than 94.6% were deleted from the analysis for the estimation of abundance index. The period for estimation of the abundance indices was shortened to 1976-2010 from the extraction analysis because the code for individual vessels was available only since 1976. Three categories, i.e. shallower or deeper gear setting (shallower HPB<7 and deeper HPB>6), Kinkai or Enyo longliner, and "early" or "late", are necessary to consider in order to determine whether analyses should be separated by each category because of the change of targeting species, operation location, effective effort and/or the logbook system.
The abundance indices were estimated by the following process;

1) Data are divided by the vessel type (Kinkai or Enyo), by gear configuration (shallower or deeper), and by prefecture of vessel register (Hokkaido & Tohoku or others) in "early" (1976-1993) and "late" (1994-2010). CPUE trends are estimated using the standardization method with GLM by each category described below.
    - 1-1-1: Kinkai with shallower setting in "early"
    - 1-1-2: Kinkai with deeper setting in "early"
    - 1-2-1: Enyo with shallower setting in "early"
    - 1-2-2: Enyo with deeper setting in "early"
    - 2-1-1: Kinkai with shallower setting in "late"
    - 2-1-2: Kinkai with deeper setting in "late"
    - 2-2-1: Enyo with shallower setting in "late"
    - 2-2-2: Enyo with deeper setting in "late"
2) Fleet categories that produced similar trends of standardized CPUE were combined and re-standardized to simplify the process. As a result, seven models are constructed to standardize CPUE, i.e.
    - 1-1-1a: Kinkai with shallower setting by Hokkaido & Tohoku prefectures in "early"
    - 1-1-2a: Kinkai with deeper setting by Hokkaido & Tohoku prefectures in "early"
    - 1-2-1: Enyo with shallower setting in "late"
    - 1-2-2: Enyo with deeper setting in "late"
    - 2-1-1a:Kinkai and Enyo with shallower setting by Hokkaido & Tohoku prefectures in "late"
    - 2-1-2a: Enyo with deeper setting by Hokkaido & Tohoku prefectures in "late"
    - 2-2-1: Enyo with shallower setting in "late"
3) Standardization models estimated by the data including Kinkai fleet with shallower setting registered in Hokkaido & Tohoku (1-1-1a and 2-1-1a) were selected for representation of abundance trends of blue shark in the North Pacific. These models

(1-1-1a and 2-1-1a) were recalculated with the data filtered by 94.6% RRZ. The standardized CPUEs as abundance indices were calculated from the weighted mean of the area indices. The weighting factor of each area was its approximate dimension.

3-2. Target effect in the CPUE standardization

The Japanese longliners changed their target species historically in the North Pacific (Yokawa, 2005). Especially the Japanese surface longliners based in Kesennuma fishing port (corresponding to the fleet of Kinkai registered in Tohoku and Hokkaido in this study) have been more frequently targeting blue shark in recent years (Yokawa, 2009; Clarke et al., 2011). The historical change of target species is one of the fundamental factors to skew the trend of the estimated abundance index. Hiraoka et al. (2012b) confirmed the existences of annual change of target species by using the directed CPUE method (Biseau, 1998), thus an additional factor is introduced into the model of CPUE standardization to adjust for this effect. Yokawa (2009) indicated the target shifted from swordfish and tunas to blue shark and used the ratio of catch of blue shark to tunas as the factor to adjust the effect of target change. However, the ratio should be affected by the annual change of stock abundance for other species also (Anonymous, 1997). so the percentile of the annual CPUE value of swordfish is used as the target effect (Chang et al., 2009). The data for swordfish catch ratio for each year was assigned into 10 categories defined by every 10^{th} percentile.

3-3. Model structure

GLMs with negative-binomial error distribution are constructed to obtain standardized CPUE for the each category of fishery defined above, respectively. In the CPUE standardization, effects of year, quarter, area (as defined by the SHARKWG; Fig. 2), target effect, prefecture and their two way interactions were initially included in the models. Because of computing power, the step-wise method with AIC could not be applied to estimate the optimal model so interaction terms were picked and used for the more important factors by preliminary analysis using a Poisson model. All model settings are shown in Table 1. Through the filtering process for the late data set, 1994-2010, almost all of the operations conducted in area 5 (Fig. 2) were rejected and only two operations remained. Thus the abundance index was estimated for operations excluding area 5.

A bootstrap method was used to calculate 95% confidence intervals of the standardized CPUE and coefficients of variation (C.V.) for estimated catch with 1000 times re-sampling.

Results

The statistical diagnosis of the three model runs for the analysis of blue shark ratio in the catch of shark (optimal, available and simple) using the data in "late" is shown in Table2. The values of residual deviance and AIC of available, which is to be used for the estimation of blue shark catch in "early", are slightly larger than the optimal but much lower than the simple. The values of the degree of freedom are more or less the same among three models. Although SST is a significant variable for both Kinkai and Enyo (Hiraoka et al., 2012b), SST is not available within the data in "early". Thus the available models (almost the same as the optimal model without SST) could extract blue shark only catch more accurately than the simple model. The extracted catch by available models was lower than other catches, which indicating the similar level (Fig. 3). The standardized CPUEs of blue shark were estimated using the filtered set by set data of the shallow setting Japanese longliners registered to Tohoku & Hokkaido area. GLMs used in analysis of data in "early" and "late" periods are shown in Table 1 (1-1-1a, 2-1-1a). The annual trend of estimated abundance index in "early" shows a general decreasing trend until 1989 when it began to increase (Table 5 and Fig 5). In contrast, that for 1994- 2005 gradually increased up to 2005, decreased until 2008, and then recovered in 2009. The effort and catch for the estimation of standardized CPUE were mostly distributed in the northwestern Pacific where the majority of catches of blue shark were obtained (Figs. 2, 3 and 4). Blue sharks for these fisheries were mainly caught between 25ºN and 45°N. The percentage of estimated catch to estimated total catch caught by Japanese longliners was showed in Table 4. A relatively higher proportion occured in "late" (65.0-30.9%) compared to "early" (12.3-31.3%). The annual residuals of GLMs for CPUE standardization in all years showed normal distributions (Fig. 7).

Discussion

Though interviews with the skippers of Japanese commercial vessel it was determined that there are many discards of blue shark which cannot be recorded in their logbooks. The catch rate reported by Kinkai fleet with shallow setting registered to Hokkaido & Tohoku region would be of high credibility. In Kesennuma port, which belongs to Miyagi prefecture and is located in the Tohoku region of Japan (Fig 1), 36-91% of Japanese shark catch has been landed during 1988 through 2009 (Kesennuma Fisheries Cooperative Association, unpub.). There were many factories processing shark meat, skin as well as bone which attained full utilization of sharks. Though these facilities were seriously damaged by the Great East Japan Earthquake, many of them are in the process of recovery now. Thus, sharks have a relatively high market value and the commercial vessels seasonally targeted shark species (Hiraoka et al., 2011; Yokawa and Ando 2011).

Takahashi et al. (2012) compared the CPUE of blue shark caught by commercial longliners to that by RTV which was mandated to report their blue shark catch from 2000 to 2010. The mean ratios of reported catch of commercial longliners to their "reference" catch throughout the analysis period were 0.75, 0.89 and 0.07 for Kinkai-shallow, Enyo-shallow and Enyo-deep set fleets, respectively. They concluded the shallow set fleets of commercial vessels should have properly reported their blue shark catch in logbooks. In addition, skipper's notes of Kinkai-shallow longliners based in Kesennuma fishing port showed that under reporting of these operations were negligible (Yokawa and Kimoto, 2012). Because the reliability of the data set using abundance indices was validated only after 2000, the filtering method (Clarke et al., 2011) was applied in order to avoid statistical problems created by high zero catch observations in the early period. Thus, in the present study, the data of shallow sets by Hokkaido & Tohoku fleets was used for the estimation of abundance indices after filtering out the remaining data including discards of blue shark using the criteria described by Clarke et al. (2011).

Kleiber et al. (2009), Clarke et al. (2011) and this study standardized CPUEs of blue shark using the same data resource of Japanese commercial longline vessels compiled by the National Research Institute of Far Seas Fisheries, however, the different data selection process and an improved model configuration were applied in this study. In Kleiber et al. (2009), standardized CPUEs of deep sets as well as shallow sets were conducted and both CPUEs were input as abundance indices. We also standardized the deep set CPUE but decided to only use sallow set of Hokkaido & Tohoku for the estimation of abundance indices because data of this fleet proved to have highest reliability among Japanese longline fleets operating in the North Pacific (Takahashi et al., 2012). Compared to the standardized CPUE series by Clarke et al. (2011), our results were smoother and had fewer fluctuations. This difference could be due to the result of the introduction of a targeting effect as a variable in this study. Though Clarke et al. (2011) reported the calculated targeting indicator showed clear trend of increase over the last ten years of their time series, which suggested an increased proportion of blue shark directed sets, they did not consider this factor when constructing model forms for estimation of the abundance index. Thus, the abundance indices of blue shark estimated in this study should be more realistic than the ones estimated by the two previous studies.

More recently, a decreasing trend of standardized CPUE of North Pacific blue shark was showed by Clarke et al. (2013) whereas an increasing trend from 1989 was obtained in our study. Although Clarke et al. (2013) used the data from onboard observers in longline fisheries, coverage rates and representativeness for the whole stock was limited as they pointed out. The number of sets across the whole Pacific was 37,774 from 1996 to 2010 and the effort was mainly distributed south of 30ºN (Clarke et al., 2013). The catch and effort of our study was mainly distributed in the northwest Pacific and a high proportion of Japanese longline catch was covered (Table 4, Figs 5 and 6). The reason for a different trend of CPUE could be the different effort distribution. Nakano (1994) revealed that relative abundance of blue sharks is lower between 0ºN and 30ºN compared to the area north of 30ºN, and he also reported size and sex segregated distribution. For sub-adults, females appeared in the area between 40ºN and 50ºN, and males between 30ºN and 40ºN. Adult sharks of both sexes appeared further south. From the biological perspective, CPUE as indicators of the population should be estimated by the catch and effort data in their main distribution ground. It is considered that the standardized CPUEs calculated in our study should be more appropriate as the abundance indices for stock assessment, however, the CPUE trend in the southern area should be given attention as an indicator of the adult population. In conclusion, the abundance indices calculated in this study are believed to represent the population trend of the north Pacific blue shark.

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Table 1 Variable explanation of each model

Model	Variable explanation†
1975-1993	
1-1-1a: Kinkai_shallow_Hokkaido&Tohoku	year, area, season, target, year*target
1-1-2a: Kinkai_deep_Hokkaido&Tohoku	year, area, season, deep-HPB
1-2-1: Enyo_shallow	year, area, season, shallow-HPB, prefecture, year*area
1-2-2: Enyo_deep	year, area, season, deep-HPB, prefecture, year*area
1994-2010	
2-1-1a: Kinkai/Enyo_shallow_Hokkaido& Tohoku	vessel type, year, area, season, target, year*target, season*target
2-1-2a: Kinkai_deep_Hokkaido&Tohoku	year, area, season, deep-HPB*, area* deep-HPB, year* deep-HPB
2-2-1: Enyo_deep	year, area, season, deep-HPB , prefecture

† year: effect of year, area: effect of area, season: effect of season, target: effect of targeting, deep-HPB: brunch line criteria of deeper setting (6-14, 14-20), shallow-HPB: brunch line criteria of shallower setting (3,4,5), vessel type: effect of vessel type (Kinkai or Enyo), prefecture: effect of prefecture (Hokkaido & Tohoku or other prefectures).

Table 2 Residual deviances and AIC values of each models

Fleet type		Residual deviance	Residual 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 3 Annual nominal, standardized (n/1000 hooks), normalized CPUEs and coefficients of variation (C.V.) for the blue shark in 1976-1993, 1994-2010.

Year	Nominal CPUE*	Standardized CPUE	Normalized CPUE	C.V. (%)
1976	16.803	15.479	1.352	2.015
1977	17.783	16.085	1.402	1.326
1978	14.964	13.828	1.210	1.601
1979	16.378	14.570	1.268	1.365
1980	17.155	15.391	1.364	1.592
1981	14.564	12.777	1.126	1.417
1982	14.478	12.634	1.107	1.332
1983	13.880	11.939	1.050	1.149
1984	11.672	10.355	0.909	1.259
1985	10.320	8.907	0.779	1.031
1986	11.827	10.470	0.912	1.126
1987	8.900	7.772	0.680	1.195
1988	9.485	8.124	0.712	1.226
1989	8.630	7.309	0.642	1.406
1990	9.282	7.697	0.672	1.352
1991	11.730	9.787	0.853	1.329
1992	12.779	10.183	0.892	1.428
1993	14.371	12.180	1.068	1.437
1994	10.867	10.785	0.659	1.714
1995	10.809	12.735	0.778	1.562
1996	13.848	12.022	0.733	1.611
1997	19.646	14.891	0.908	1.600
1998	18.732	15.051	0.923	1.698
1999	23.406	16.034	0.982	1.783
2000	26.900	16.428	1.000	1.749
2001	32.051	18.403	1.120	1.811
2002	29.838	18.311	1.115	1.697
2003	34.643	19.583	1.188	1.667
2004	31.507	18.021	1.098	1.455
2005	39.499	20.091	1.225	2.146
2006	36.595	18.144	1.102	2.217
2007	25.388	14.653	0.893	2.008
2008	25.213	14.261	0.867	2.375
2009	35.594	19.782	1.202	2.652
2010	32.925	19.914	1.208	2.371

*Nominal CPUE calculated by annual total catch / annual total hook

Table 4 Percentage of estimated catches (numbers of sharks) calculated using standardized CPUE

Year	Estimated catches using standardized CPUE	Estimated total catches of blue shark caught by Japanese longliners	Percentage (%)
1976	228,451	1,454,419	15.7
1977	287,413	1,869,191	15.4
1978	238,650	1,596,632	14.9
1979	279,510	1,922,841	14.5
1980	272,153	1,996,902	13.6
1981	244,380	1,983,190	12.3
1982	208,506	1,409,727	14.8
1983	272,114	1,400,305	19.4
1984	238,817	1,297,093	18.4
1985	249,109	1,219,536	20.4
1986	304,751	1,062,046	28.7
1987	242,372	850,302	28.5
1988	212,721	955,674	22.3
1989	198,392	1,023,468	19.4
1990	189,235	774,034	24.4
1991	236,815	860,707	27.5
1992	239,919	766,455	31.3
1993	265,999	966,062	27.5
1994	281,046	847,146	33.2
1995	289,689	936,486	30.9
1996	293,455	768,482	38.2
1997	367,364	860,176	42.7
1998	382,990	851,491	45.0
1999	443,647	805,037	55.1
2000	606,199	970,369	62.5
2001	684,657	1,043,870	65.6
2002	539,220	852,723	63.2
2003	593,546	961,494	61.7
2004	537,597	875,595	61.4
2005	618,625	1,021,334	60.6
2006	546,328	957,219	57.1
2007	478,382	817,230	58.5
2008	385,650	658,037	58.6
2009	459,860	707,513	65.0
2010	383,247	802,981	47.7

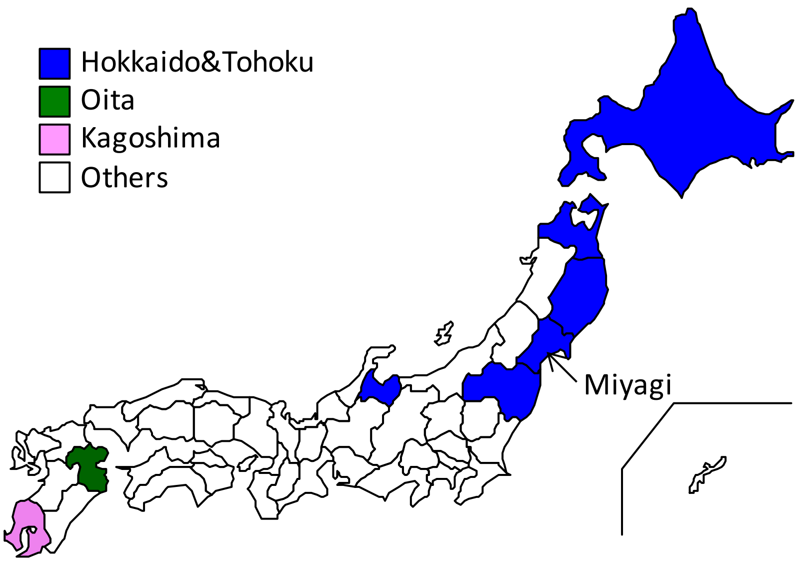


Figure 1 Japanese prefectural border and regional category in this study.

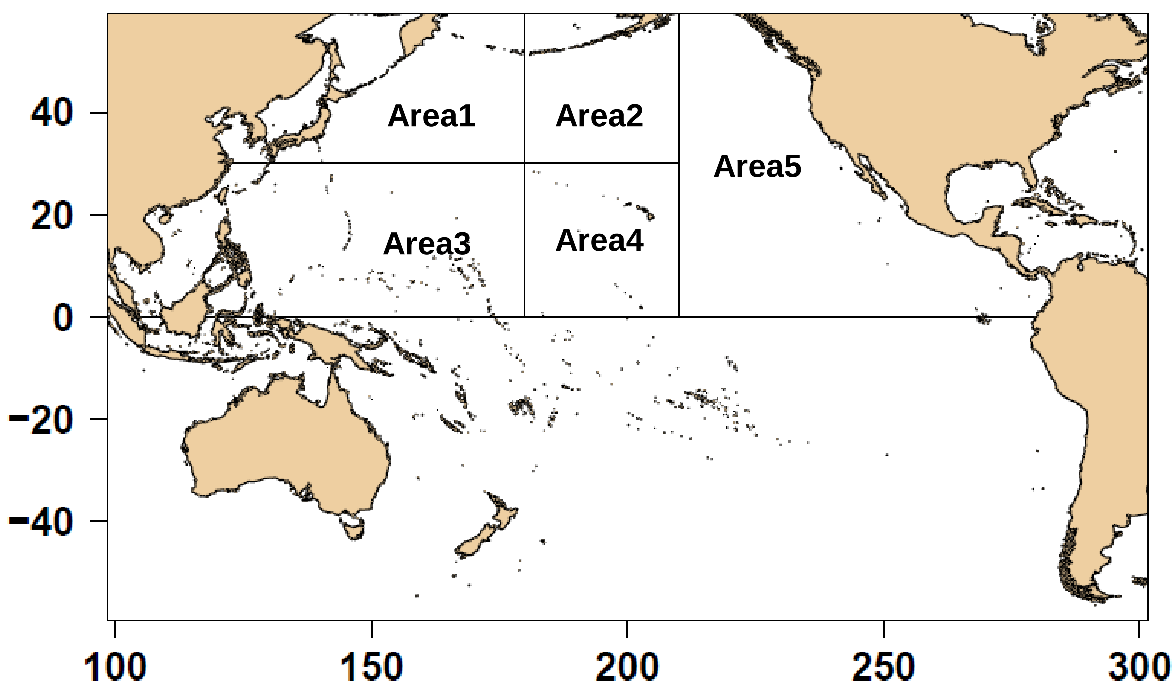


Figure 2 Area classification in this study.

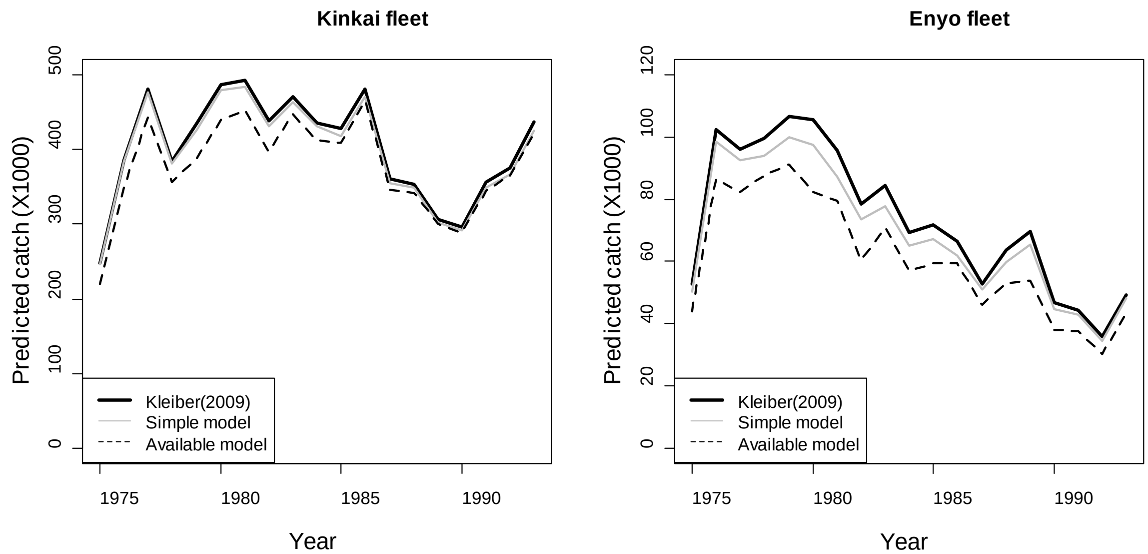


Figure 3 Predicted catch of blue shark estimated by each model for Kinkai fleet (left) and Enyo fleet (right) in the North Pacific during 1975 to 1993.

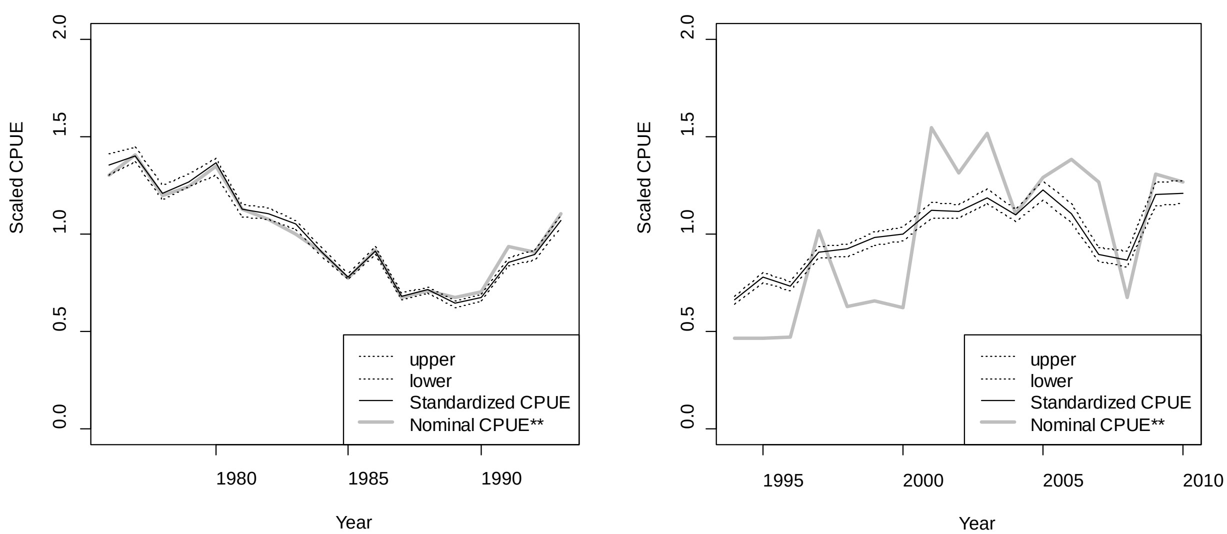


Figure 4 Trend of Standardized CPUE and their 95% confidence interval by 1000 times re-sampling in "early" (1976-1993: left), and in "late" (1994-2010: right). All values were normalized to their mean which set at 1.0.

**Nominal CPUE calculated from the weighted mean of the area indices same as Standardized CPUE

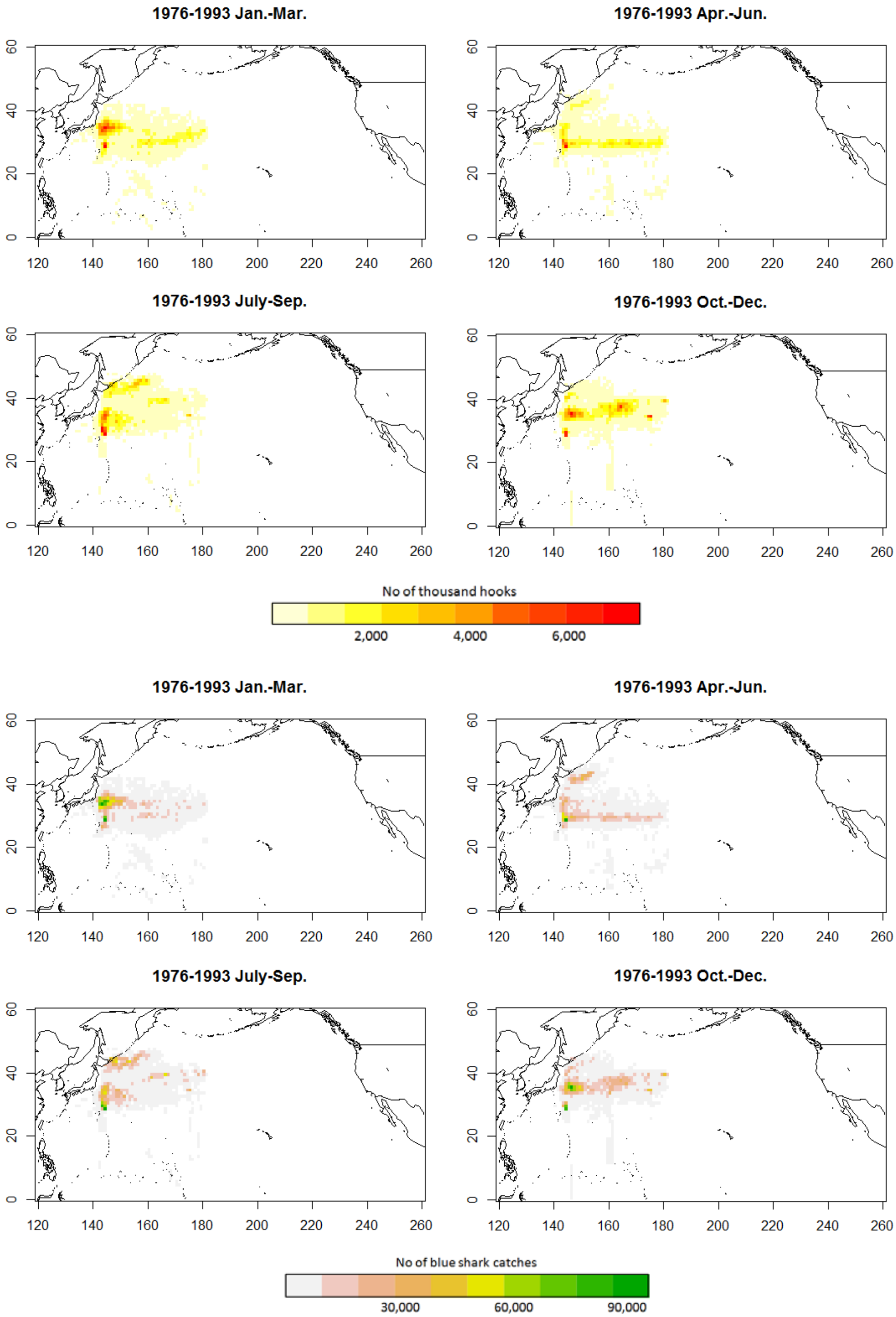


Figure 5 Geographical distribution of fishing effort (upper) and blue shark catch (lower) by season for estimating abundance indices in "early".

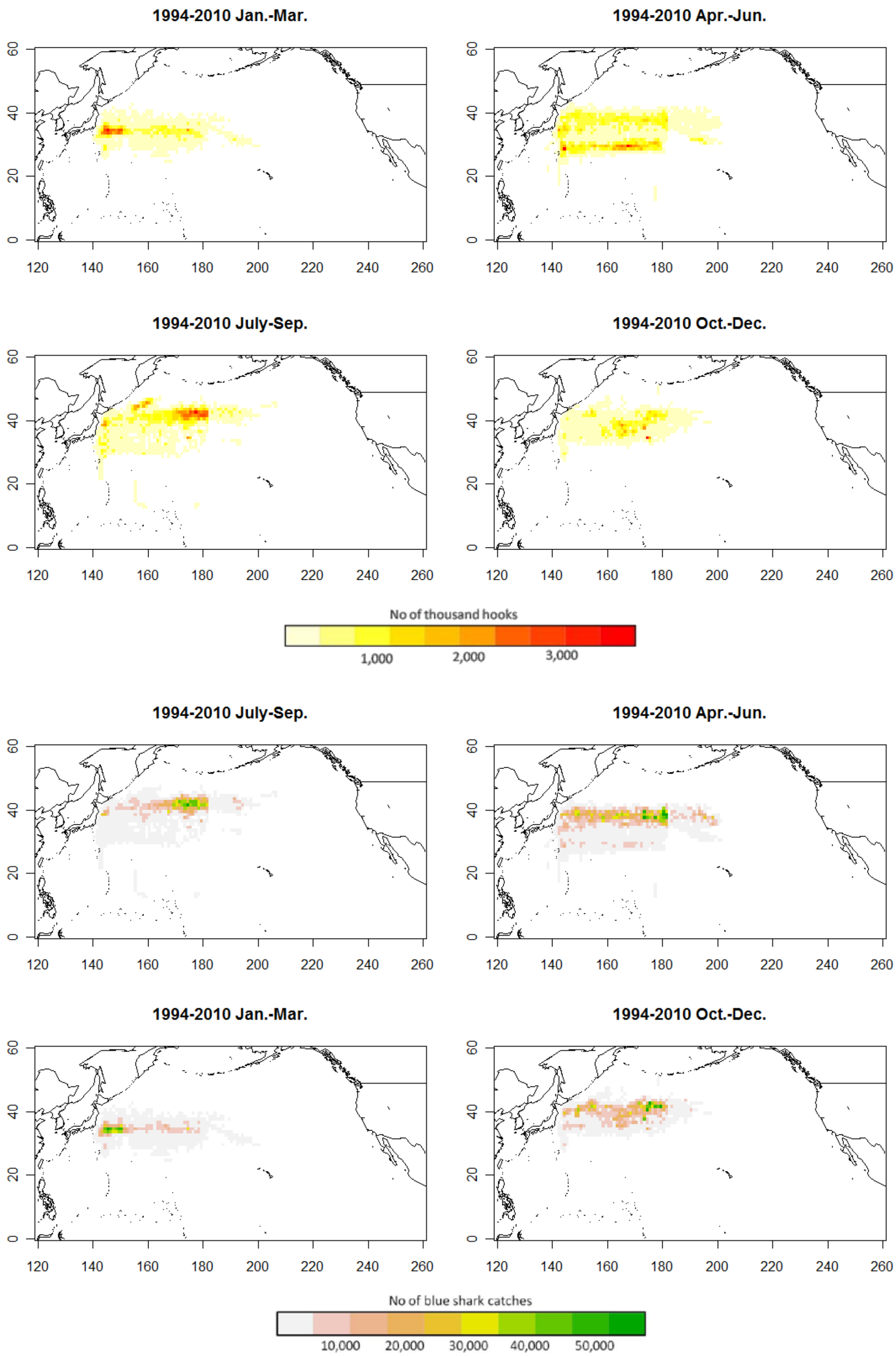


Figure 6 Geographical distribution of fishing effort (upper) and blue shark catch (lower) by season for estimating abundance indices in "late".

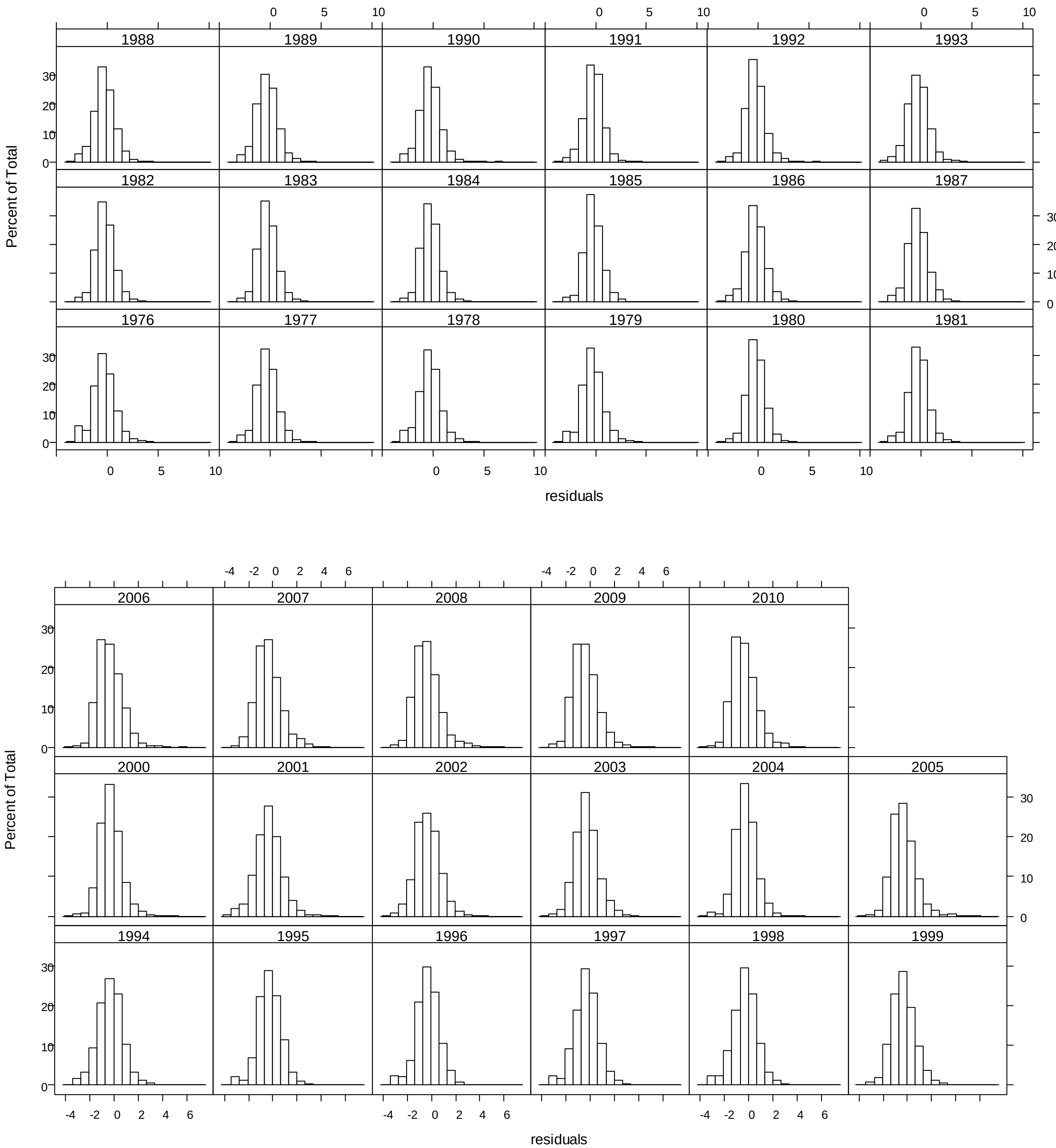
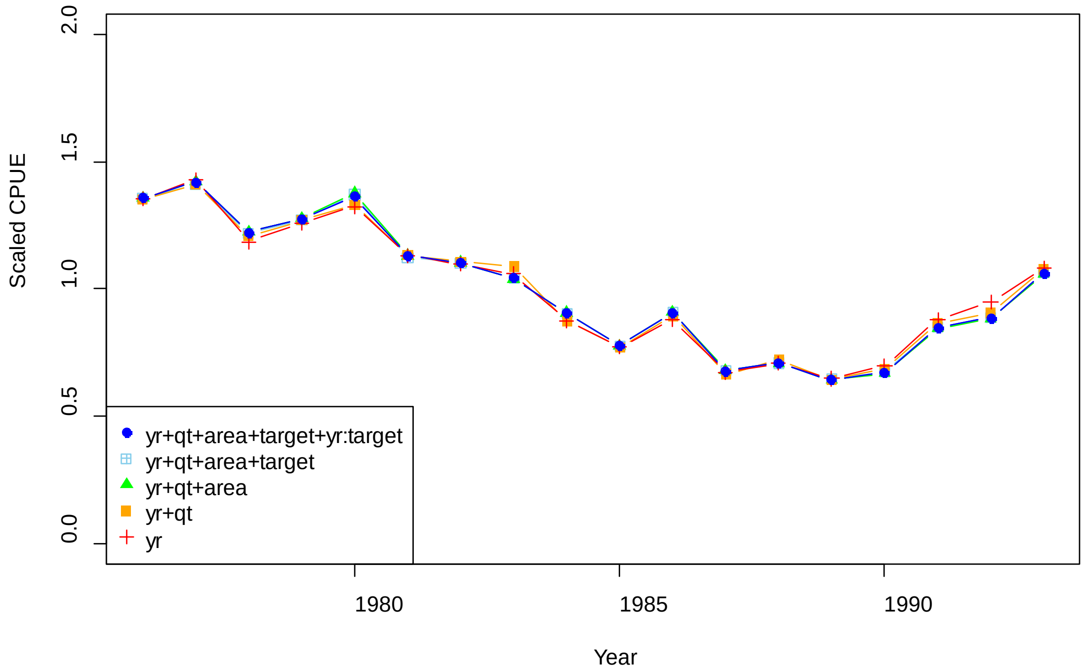
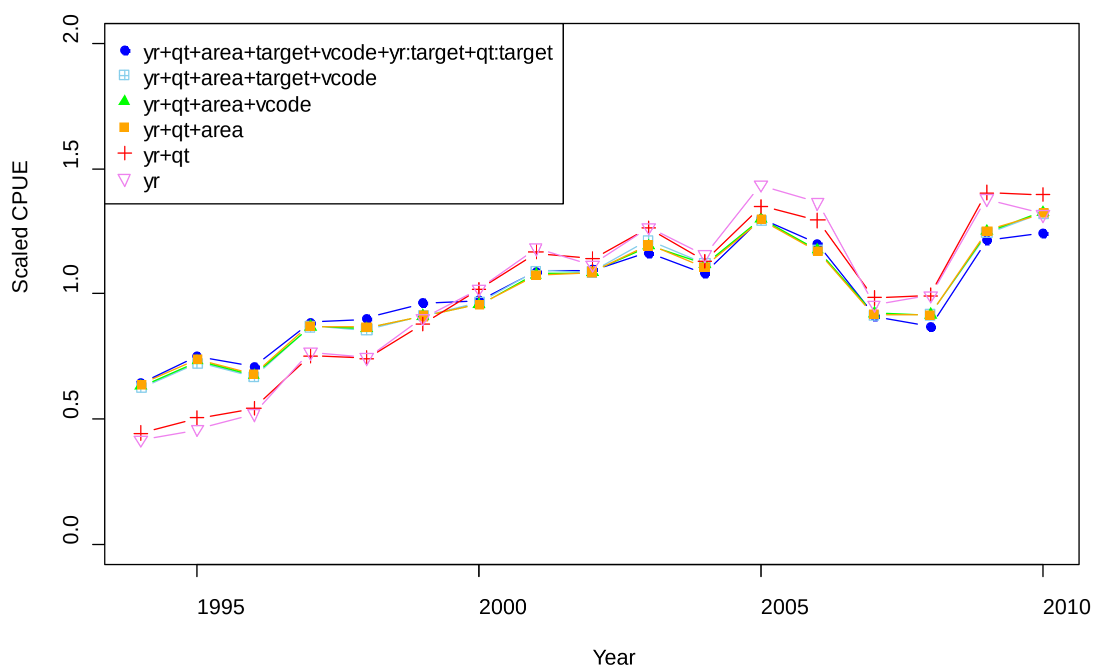


Figure 7 Annual residual patterns of GLMs for abundance indices in "early" (1976-1993: upper), and in "late" (1994-2010: lower).

Appendix I: Comparison of nested models in "early" and "late".





Appendix II: Summary outputs of GLM analyses from R

I. Early (1976 -1993)

```
Call:
glm.nb(formula = blshrk ~ as.factor(year) + as.factor(qt) + as.factor(area) +
    as.factor(target3) + as.factor(year):as.factor(target3) +
    offset(log(hook)), data = temp, init.theta = 1.454238318,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.5195  -0.9109  -0.3215   0.3114   9.5039

Coefficients:
                                      Estimate Std. Error  z value Pr(>|z|)
(Intercept)                          -4.015122   0.033918 -118.379  < 2e-16 ***
as.factor(year)1977                   0.582687   0.045935   12.685  < 2e-16 ***
as.factor(year)1978                   0.182149   0.047005    3.875 0.000107 ***
as.factor(year)1979                   0.370486   0.046369    7.990 1.35e-15 ***
as.factor(year)1980                   0.215486   0.045090    4.779 1.76e-06 ***
as.factor(year)1981                   0.112500   0.043010    2.616 0.008905 **
as.factor(year)1982                  -0.049504   0.047856   -1.034 0.300925
as.factor(year)1983                  -0.179298   0.045996   -3.898 9.69e-05 ***
as.factor(year)1984                  -0.263919   0.045818   -5.760 8.40e-09 ***
as.factor(year)1985                  -0.421242   0.044921   -9.377  < 2e-16 ***
as.factor(year)1986                  -0.258732   0.044694   -5.789 7.08e-09 ***
as.factor(year)1987                  -0.660055   0.044722  -14.759  < 2e-16 ***
as.factor(year)1988                  -0.627214   0.046857  -13.386  < 2e-16 ***
as.factor(year)1989                  -0.943883   0.047129  -20.028  < 2e-16 ***
as.factor(year)1990                  -0.808370   0.048425  -16.693  < 2e-16 ***
as.factor(year)1991                  -0.506564   0.048820  -10.376  < 2e-16 ***
as.factor(year)1992                  -0.418871   0.049200   -8.514  < 2e-16 ***
as.factor(year)1993                  -0.184390   0.049905   -3.695 0.000220 ***
as.factor(qt)2                        0.242626   0.006835   35.497  < 2e-16 ***
as.factor(qt)3                        0.362760   0.007793   46.548  < 2e-16 ***
as.factor(qt)4                       -0.139885   0.007252  -19.288  < 2e-16 ***
as.factor(area)3                     -0.398930   0.006074  -65.677  < 2e-16 ***
as.factor(target3)2                   0.086288   0.047758    1.807 0.070795 .
as.factor(target3)3                  -0.033400   0.047770   -0.699 0.484433
as.factor(target3)4                  -0.211930   0.047928   -4.422 9.79e-06 ***
as.factor(target3)5                  -0.081070   0.047730   -1.699 0.089412 .
as.factor(target3)6                  -0.037166   0.047717   -0.779 0.436048
as.factor(target3)7                  -0.107086   0.048040   -2.229 0.025806 *
as.factor(target3)8                   0.084574   0.047634    1.775 0.075817 .
as.factor(target3)9                   0.190065   0.047654    3.988 6.65e-05 ***
as.factor(target3)10                  0.397511   0.047873    8.304  < 2e-16 ***
as.factor(year)1977:as.factor(target3)2  -0.677036   0.065232  -10.379  < 2e-16 ***
as.factor(year)1978:as.factor(target3)2  -0.823593   0.066897  -12.311  < 2e-16 ***
as.factor(year)1979:as.factor(target3)2  -0.638497   0.065947   -9.682  < 2e-16 ***
as.factor(year)1980:as.factor(target3)2  -0.394555   0.068059   -5.797 6.74e-09 ***
as.factor(year)1981:as.factor(target3)2  -0.134304   0.069076   -1.944 0.051862 .
as.factor(year)1982:as.factor(target3)2  -0.274387   0.068817   -3.987 6.68e-05 ***
as.factor(year)1983:as.factor(target3)2  -0.082117   0.065249   -1.259 0.208205
as.factor(year)1984:as.factor(target3)2  -0.117087   0.064854   -1.805 0.071014 .
as.factor(year)1985:as.factor(target3)2  -0.094111   0.063475   -1.483 0.138170
as.factor(year)1986:as.factor(target3)2  -0.030113   0.063361   -0.475 0.634606
as.factor(year)1987:as.factor(target3)2   0.056673   0.063391    0.894 0.371315
as.factor(year)1988:as.factor(target3)2  -0.005759   0.066276   -0.087 0.930756
as.factor(year)1989:as.factor(target3)2  -0.087877   0.066754   -1.316 0.188028
as.factor(year)1990:as.factor(target3)2   0.227627   0.068690    3.314 0.000920 ***
as.factor(year)1991:as.factor(target3)2  -0.135374   0.069173   -1.957 0.050342 .
as.factor(year)1992:as.factor(target3)2  -0.002653   0.069024   -0.038 0.969345
as.factor(year)1993:as.factor(target3)2  -0.148704   0.070411   -2.112 0.034691 *
as.factor(year)1977:as.factor(target3)3  -0.519164   0.065268   -7.954 1.80e-15 ***
as.factor(year)1978:as.factor(target3)3  -0.361896   0.066686   -5.427 5.73e-08 ***
as.factor(year)1979:as.factor(target3)3  -0.491763   0.065746   -7.480 7.45e-14 ***
as.factor(year)1980:as.factor(target3)3  -0.436404   0.065545   -6.658 2.77e-11 ***
as.factor(year)1981:as.factor(target3)3  -0.196264   0.063412   -3.095 0.001968 **
as.factor(year)1982:as.factor(target3)3  -0.070006   0.068370   -1.024 0.305867
as.factor(year)1983:as.factor(target3)3   0.103759   0.065186    1.592 0.111448
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as.factor(year)1984:as.factor(target3)3   0.082482   0.065239    1.264 0.206116    
as.factor(year)1985:as.factor(target3)3   0.058347   0.063968    0.912 0.361707    
as.factor(year)1986:as.factor(target3)3  -0.052024   0.063406   -0.820 0.411936    
as.factor(year)1987:as.factor(target3)3   0.213092   0.063330    3.365 0.000766 ***
as.factor(year)1988:as.factor(target3)3   0.050674   0.066547    0.761 0.446374    
as.factor(year)1989:as.factor(target3)3   0.191882   0.066590    2.882 0.003957 ** 
as.factor(year)1990:as.factor(target3)3   0.363903   0.068648    5.301 1.15e-07 ***
as.factor(year)1991:as.factor(target3)3   0.023512   0.069317    0.339 0.734462    
as.factor(year)1992:as.factor(target3)3   0.135586   0.070060    1.935 0.052957 .  
as.factor(year)1993:as.factor(target3)3   0.003224   0.070603    0.046 0.963575    
as.factor(year)1977:as.factor(target3)4  -0.396335   0.065347   -6.065 1.32e-09 ***
as.factor(year)1978:as.factor(target3)4  -0.019354   0.066838   -0.290 0.772143    
as.factor(year)1979:as.factor(target3)4  -0.173427   0.066023   -2.627 0.008620 ** 
as.factor(year)1980:as.factor(target3)4   0.059530   0.065671    0.906 0.364676    
as.factor(year)1981:as.factor(target3)4  -0.012482   0.063744   -0.196 0.844759    
as.factor(year)1982:as.factor(target3)4   0.274493   0.068254    4.022 5.78e-05 ***
as.factor(year)1983:as.factor(target3)4   0.230523   0.065336    3.528 0.000418 ***
as.factor(year)1984:as.factor(target3)4   0.046475   0.065168    0.713 0.475748    
as.factor(year)1985:as.factor(target3)4   0.012629   0.063926    0.198 0.843399    
as.factor(year)1986:as.factor(target3)4   0.038110   0.063475    0.600 0.548245    
as.factor(year)1987:as.factor(target3)4   0.267228   0.063529    4.206 2.59e-05 ***
as.factor(year)1988:as.factor(target3)4   0.345729   0.066485    5.200 1.99e-07 ***
as.factor(year)1989:as.factor(target3)4   0.490375   0.066784    7.343 2.09e-13 ***
as.factor(year)1990:as.factor(target3)4   0.478895   0.068835    6.957 3.47e-12 ***
as.factor(year)1991:as.factor(target3)4   0.357857   0.069353    5.160 2.47e-07 ***
as.factor(year)1992:as.factor(target3)4   0.246595   0.069744    3.536 0.000407 ***
as.factor(year)1993:as.factor(target3)4   0.276596   0.070753    3.909 9.26e-05 ***
as.factor(year)1977:as.factor(target3)5  -0.439722   0.064898   -6.776 1.24e-11 ***
as.factor(year)1978:as.factor(target3)5  -0.171565   0.066738   -2.571 0.010149 *  
as.factor(year)1979:as.factor(target3)5  -0.425502   0.065866   -6.460 1.05e-10 ***
as.factor(year)1980:as.factor(target3)5  -0.056535   0.065402   -0.864 0.387350    
as.factor(year)1981:as.factor(target3)5  -0.116144   0.063423   -1.831 0.067064 .  
as.factor(year)1982:as.factor(target3)5  -0.115101   0.068469   -1.681 0.092749 .  
as.factor(year)1983:as.factor(target3)5   0.051959   0.065194    0.797 0.425459    
as.factor(year)1984:as.factor(target3)5  -0.089296   0.065092   -1.372 0.170108    
as.factor(year)1985:as.factor(target3)5  -0.150259   0.063717   -2.358 0.018364 *  
as.factor(year)1986:as.factor(target3)5  -0.139331   0.063484   -2.195 0.028183 *  
as.factor(year)1987:as.factor(target3)5   0.031614   0.063328    0.499 0.617631    
as.factor(year)1988:as.factor(target3)5   0.204232   0.066371    3.077 0.002090 ** 
as.factor(year)1989:as.factor(target3)5   0.405088   0.066710    6.072 1.26e-09 ***
as.factor(year)1990:as.factor(target3)5   0.235177   0.068408    3.438 0.000586 ***
as.factor(year)1991:as.factor(target3)5   0.249680   0.069043    3.616 0.000299 ***
as.factor(year)1992:as.factor(target3)5  -0.005139   0.069735   -0.074 0.941250    
as.factor(year)1993:as.factor(target3)5   0.055462   0.070642    0.785 0.432383    
as.factor(year)1977:as.factor(target3)6  -0.549890   0.065642   -8.377  < 2e-16 ***
as.factor(year)1978:as.factor(target3)6  -0.329682   0.066659   -4.946 7.58e-07 ***
as.factor(year)1979:as.factor(target3)6  -0.484881   0.065849   -7.364 1.79e-13 ***
as.factor(year)1980:as.factor(target3)6  -0.115788   0.065533   -1.767 0.077250 .  
as.factor(year)1981:as.factor(target3)6  -0.341936   0.063452   -5.389 7.09e-08 ***
as.factor(year)1982:as.factor(target3)6  -0.136893   0.068309   -2.004 0.045067 *  
as.factor(year)1983:as.factor(target3)6  -0.086477   0.065195   -1.326 0.184693    
as.factor(year)1984:as.factor(target3)6  -0.096833   0.064958   -1.491 0.136040    
as.factor(year)1985:as.factor(target3)6  -0.220041   0.063736   -3.452 0.000556 ***
as.factor(year)1986:as.factor(target3)6  -0.096763   0.063324   -1.528 0.126495    
as.factor(year)1987:as.factor(target3)6  -0.005696   0.063361   -0.090 0.928364    
as.factor(year)1988:as.factor(target3)6  -0.031620   0.066349   -0.477 0.633667    
as.factor(year)1989:as.factor(target3)6   0.408045   0.066614    6.125 9.04e-10 ***
as.factor(year)1990:as.factor(target3)6   0.204950   0.068631    2.986 0.002824 ** 
as.factor(year)1991:as.factor(target3)6   0.046148   0.069126    0.668 0.504390    
as.factor(year)1992:as.factor(target3)6   0.075870   0.069613    1.090 0.275761    
as.factor(year)1993:as.factor(target3)6   0.101045   0.070423    1.435 0.151335    
as.factor(year)1977:as.factor(target3)7  -0.515827   0.065463   -7.880 3.28e-15 ***
as.factor(year)1978:as.factor(target3)7  -0.138699   0.066836   -2.075 0.037967 *  
as.factor(year)1979:as.factor(target3)7  -0.432571   0.066052   -6.549 5.80e-11 ***
as.factor(year)1980:as.factor(target3)7  -0.049885   0.065610   -0.760 0.447061    
as.factor(year)1981:as.factor(target3)7  -0.357653   0.063772   -5.608 2.04e-08 ***
as.factor(year)1982:as.factor(target3)7  -0.151018   0.068530   -2.204 0.027546 *  
as.factor(year)1983:as.factor(target3)7   0.025490   0.065401    0.390 0.696728    
as.factor(year)1984:as.factor(target3)7  -0.142030   0.065328   -2.174 0.029697 *  
as.factor(year)1985:as.factor(target3)7  -0.109233   0.063914   -1.709 0.087439 .  
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as.factor(year)1986:as.factor(target3)7  -0.134642   0.063664   -2.115 0.034438 *
as.factor(year)1987:as.factor(target3)7   0.087472   0.063668    1.374 0.169481
as.factor(year)1988:as.factor(target3)7   0.115322   0.066731    1.728 0.083956 .
as.factor(year)1989:as.factor(target3)7   0.469914   0.066864    7.028 2.10e-12 ***
as.factor(year)1990:as.factor(target3)7   0.252398   0.069277    3.643 0.000269 ***
as.factor(year)1991:as.factor(target3)7   0.295011   0.069536    4.243 2.21e-05 ***
as.factor(year)1992:as.factor(target3)7   0.203791   0.069814    2.919 0.003511 **
as.factor(year)1993:as.factor(target3)7  -0.059378   0.071143   -0.835 0.403929
as.factor(year)1977:as.factor(target3)8  -0.816151   0.065174  -12.523  < 2e-16 ***
as.factor(year)1978:as.factor(target3)8  -0.362425   0.066684   -5.435 5.48e-08 ***
as.factor(year)1979:as.factor(target3)8  -0.431208   0.065679   -6.565 5.19e-11 ***
as.factor(year)1980:as.factor(target3)8  -0.340567   0.065388   -5.208 1.90e-07 ***
as.factor(year)1981:as.factor(target3)8  -0.424881   0.063362   -6.706 2.01e-11 ***
as.factor(year)1982:as.factor(target3)8  -0.321445   0.068185   -4.714 2.43e-06 ***
as.factor(year)1983:as.factor(target3)8  -0.221051   0.064940   -3.404 0.000664 ***
as.factor(year)1984:as.factor(target3)8  -0.171476   0.064908   -2.642 0.008246 **
as.factor(year)1985:as.factor(target3)8  -0.204247   0.063689   -3.207 0.001342 **
as.factor(year)1986:as.factor(target3)8  -0.166906   0.063292   -2.637 0.008362 **
as.factor(year)1987:as.factor(target3)8  -0.132867   0.063324   -2.098 0.035886 *
as.factor(year)1988:as.factor(target3)8  -0.238790   0.066241   -3.605 0.000312 ***
as.factor(year)1989:as.factor(target3)8   0.243136   0.066584    3.652 0.000261 ***
as.factor(year)1990:as.factor(target3)8  -0.128614   0.068731   -1.871 0.061308 .
as.factor(year)1991:as.factor(target3)8   0.078921   0.069118    1.142 0.253529
as.factor(year)1992:as.factor(target3)8  -0.093276   0.069595   -1.340 0.180158
as.factor(year)1993:as.factor(target3)8  -0.091456   0.070332   -1.300 0.193483
as.factor(year)1977:as.factor(target3)9  -0.840802   0.065245  -12.887  < 2e-16 ***
as.factor(year)1978:as.factor(target3)9  -0.346350   0.066557   -5.204 1.95e-07 ***
as.factor(year)1979:as.factor(target3)9  -0.678373   0.065841  -10.303  < 2e-16 ***
as.factor(year)1980:as.factor(target3)9  -0.291846   0.065499   -4.456 8.36e-06 ***
as.factor(year)1981:as.factor(target3)9  -0.636666   0.063472  -10.031  < 2e-16 ***
as.factor(year)1982:as.factor(target3)9  -0.360173   0.068243   -5.278 1.31e-07 ***
as.factor(year)1983:as.factor(target3)9  -0.322536   0.065361   -4.935 8.03e-07 ***
as.factor(year)1984:as.factor(target3)9  -0.406281   0.064876   -6.262 3.79e-10 ***
as.factor(year)1985:as.factor(target3)9  -0.283136   0.063613   -4.451 8.55e-06 ***
as.factor(year)1986:as.factor(target3)9  -0.311177   0.063299   -4.916 8.83e-07 ***
as.factor(year)1987:as.factor(target3)9  -0.403797   0.063399   -6.369 1.90e-10 ***
as.factor(year)1988:as.factor(target3)9  -0.335233   0.066413   -5.048 4.47e-07 ***
as.factor(year)1989:as.factor(target3)9   0.137396   0.066547    2.065 0.038958 *
as.factor(year)1990:as.factor(target3)9  -0.071240   0.068593   -1.039 0.299002
as.factor(year)1991:as.factor(target3)9  -0.226266   0.069116   -3.274 0.001061 **
as.factor(year)1992:as.factor(target3)9  -0.200050   0.069522   -2.878 0.004008 **
as.factor(year)1993:as.factor(target3)9  -0.176338   0.070445   -2.503 0.012307 *
as.factor(year)1977:as.factor(target3)10 -0.709673   0.065300  -10.868  < 2e-16 ***
as.factor(year)1978:as.factor(target3)10 -0.379303   0.066803   -5.678 1.36e-08 ***
as.factor(year)1979:as.factor(target3)10 -0.591796   0.065922   -8.977  < 2e-16 ***
as.factor(year)1980:as.factor(target3)10 -0.437982   0.065592   -6.677 2.43e-11 ***
as.factor(year)1981:as.factor(target3)10 -0.732244   0.063687  -11.498  < 2e-16 ***
as.factor(year)1982:as.factor(target3)10 -0.351489   0.068534   -5.129 2.92e-07 ***
as.factor(year)1983:as.factor(target3)10 -0.432290   0.065333   -6.617 3.67e-11 ***
as.factor(year)1984:as.factor(target3)10 -0.439063   0.065229   -6.731 1.68e-11 ***
as.factor(year)1985:as.factor(target3)10 -0.312528   0.063759   -4.902 9.50e-07 ***
as.factor(year)1986:as.factor(target3)10 -0.462719   0.063553   -7.281 3.32e-13 ***
as.factor(year)1987:as.factor(target3)10 -0.381587   0.063614   -5.998 1.99e-09 ***
as.factor(year)1988:as.factor(target3)10 -0.249116   0.066614   -3.740 0.000184 ***
as.factor(year)1989:as.factor(target3)10 -0.270696   0.066864   -4.048 5.16e-05 ***
as.factor(year)1990:as.factor(target3)10 -0.464677   0.068933   -6.741 1.57e-11 ***
as.factor(year)1991:as.factor(target3)10 -0.229870   0.069267   -3.319 0.000905 ***
as.factor(year)1992:as.factor(target3)10 -0.326844   0.069661   -4.692 2.71e-06 ***
as.factor(year)1993:as.factor(target3)10 -0.471082   0.070795   -6.654 2.85e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(1.4542) family taken to be 1)

    Null deviance: 161081  on 121108  degrees of freedom
Residual deviance: 136689  on 120925  degrees of freedom
AIC: 1095652

Number of Fisher Scoring iterations: 1
```

Theta: 1.45424
Std. Err.: 0.00588

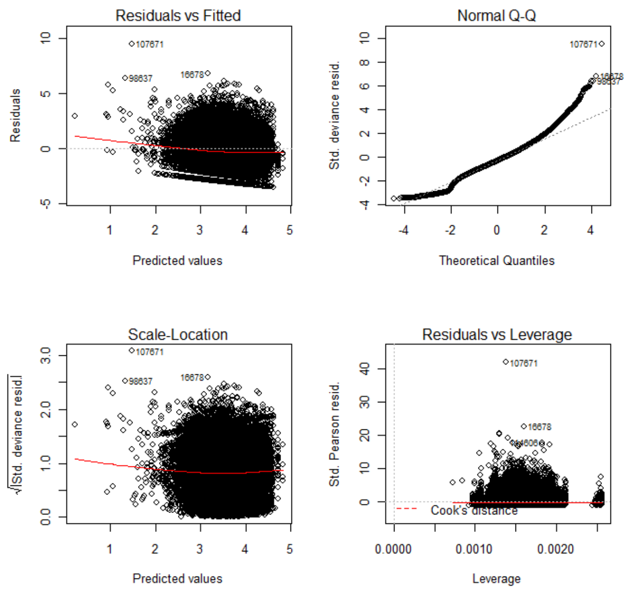
2 x log-likelihood: -1095282.20400

Analysis of Deviance Table (Type II tests)

Response: blshrk

	LR Chisq	Df	Pr(>Chisq)	
as.factor(year)	10736.5	17	< 2.2e-16	***
as.factor(qt)	4717.3	3	< 2.2e-16	***
as.factor(area)	4413.1	1	< 2.2e-16	***
as.factor(target3)	482.2	9	< 2.2e-16	***
as.factor(year):as.factor(target3)	2334.4	153	< 2.2e-16	***

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



II. Late(1994 -2010)
Call:
glm.nb(formula = blshrk ~ as.factor(year) + as.factor(qt) + as.factor(area) +
as.factor(target3) + as.factor(gyogyoucode) + as.factor(year):as.factor(target3) +
as.factor(qt):as.factor(target3) + offset(log(hook)), data = temp,
init.theta = 1.162751571, link = log)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-3.6767	-0.9744	-0.3727	0.2756	6.9832

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-4.469756	0.062360	-71.676	< 2e-16	***
as.factor(year)1995	0.175155	0.055067	3.181	0.001469	**
as.factor(year)1996	0.539024	0.054256	9.935	< 2e-16	***
as.factor(year)1997	0.756351	0.056223	13.453	< 2e-16	***
as.factor(year)1998	0.819558	0.055478	14.773	< 2e-16	***
as.factor(year)1999	0.891950	0.055982	15.933	< 2e-16	***
as.factor(year)2000	0.891166	0.054933	16.223	< 2e-16	***
as.factor(year)2001	0.957117	0.055288	17.312	< 2e-16	***
as.factor(year)2002	0.983144	0.058100	16.921	< 2e-16	***
as.factor(year)2003	0.849897	0.059249	14.345	< 2e-16	***
as.factor(year)2004	0.978273	0.060037	16.294	< 2e-16	***

as.factor(year)2005	1.309461	0.061874	21.163	< 2e-16	***
as.factor(year)2006	1.155608	0.061876	18.676	< 2e-16	***
as.factor(year)2007	1.030402	0.059257	17.389	< 2e-16	***
as.factor(year)2008	0.708692	0.063565	11.149	< 2e-16	***
as.factor(year)2009	1.184376	0.066178	17.897	< 2e-16	***
as.factor(year)2010	0.885381	0.068068	13.007	< 2e-16	***
as.factor(qt)2	0.827072	0.054715	15.116	< 2e-16	***
as.factor(qt)3	0.611346	0.053915	11.339	< 2e-16	***
as.factor(qt)4	-0.468604	0.056383	-8.311	< 2e-16	***
as.factor(area)2	-0.045581	0.019710	-2.313	0.020746	*
as.factor(area)3	-1.091956	0.011361	-96.118	< 2e-16	***
as.factor(area)4	-1.729146	0.036500	-47.373	< 2e-16	***
as.factor(target3)2	0.026329	0.081469	0.323	0.746563	
as.factor(target3)3	-0.030240	0.079179	-0.382	0.702524	
as.factor(target3)4	0.201888	0.076361	2.644	0.008196	**
as.factor(target3)5	0.285186	0.076043	3.750	0.000177	***
as.factor(target3)6	0.449346	0.075263	5.970	2.37e-09	***
as.factor(target3)7	0.440334	0.075979	5.795	6.81e-09	***
as.factor(target3)8	0.503136	0.075460	6.668	2.60e-11	***
as.factor(target3)9	0.602384	0.074354	8.102	5.43e-16	***
as.factor(target3)10	0.726483	0.073539	9.879	< 2e-16	***
as.factor(gyogyoucode)2	-0.080612	0.009735	-8.280	< 2e-16	***
as.factor(year)1995:as.factor(target3)2	0.179573	0.077437	2.319	0.020397	*
as.factor(year)1996:as.factor(target3)2	-0.171815	0.076823	-2.237	0.025318	*
as.factor(year)1997:as.factor(target3)2	-0.102133	0.078768	-1.297	0.194758	
as.factor(year)1998:as.factor(target3)2	-0.094166	0.078245	-1.203	0.228795	
as.factor(year)1999:as.factor(target3)2	-0.027192	0.078535	-0.346	0.729164	
as.factor(year)2000:as.factor(target3)2	-0.048663	0.076886	-0.633	0.526781	
as.factor(year)2001:as.factor(target3)2	-0.033185	0.077669	-0.427	0.669193	
as.factor(year)2002:as.factor(target3)2	-0.125434	0.080793	-1.553	0.120534	
as.factor(year)2003:as.factor(target3)2	0.112713	0.082924	1.359	0.174071	
as.factor(year)2004:as.factor(target3)2	0.055249	0.084179	0.656	0.511613	
as.factor(year)2005:as.factor(target3)2	0.165103	0.087138	1.895	0.058129	.
as.factor(year)2006:as.factor(target3)2	0.286760	0.089142	3.217	0.001296	**
as.factor(year)2007:as.factor(target3)2	-0.044085	0.084132	-0.524	0.600276	
as.factor(year)2008:as.factor(target3)2	0.229042	0.088986	2.574	0.010055	*
as.factor(year)2009:as.factor(target3)2	0.001481	0.092145	0.016	0.987174	
as.factor(year)2010:as.factor(target3)2	0.274849	0.096452	2.850	0.004377	**
as.factor(year)1995:as.factor(target3)3	0.195450	0.078675	2.484	0.012982	*
as.factor(year)1996:as.factor(target3)3	-0.131528	0.079343	-1.658	0.097376	.
as.factor(year)1997:as.factor(target3)3	-0.344262	0.080746	-4.264	2.01e-05	***
as.factor(year)1998:as.factor(target3)3	-0.225305	0.079425	-2.837	0.004558	**
as.factor(year)1999:as.factor(target3)3	-0.092790	0.079846	-1.162	0.245194	
as.factor(year)2000:as.factor(target3)3	-0.192539	0.078179	-2.463	0.013786	*
as.factor(year)2001:as.factor(target3)3	-0.110489	0.078264	-1.412	0.158023	
as.factor(year)2002:as.factor(target3)3	-0.026924	0.082148	-0.328	0.743095	
as.factor(year)2003:as.factor(target3)3	0.200448	0.083645	2.396	0.016557	*
as.factor(year)2004:as.factor(target3)3	-0.071324	0.084799	-0.841	0.400294	
as.factor(year)2005:as.factor(target3)3	0.043648	0.087756	0.497	0.618919	
as.factor(year)2006:as.factor(target3)3	0.160102	0.088711	1.805	0.071113	.
as.factor(year)2007:as.factor(target3)3	-0.172809	0.084101	-2.055	0.039901	*
as.factor(year)2008:as.factor(target3)3	-0.025230	0.089747	-0.281	0.778612	
as.factor(year)2009:as.factor(target3)3	-0.034530	0.093184	-0.371	0.710972	
as.factor(year)2010:as.factor(target3)3	0.078841	0.095703	0.824	0.410045	
as.factor(year)1995:as.factor(target3)4	0.068616	0.078007	0.880	0.379070	
as.factor(year)1996:as.factor(target3)4	-0.420763	0.077853	-5.405	6.50e-08	***
as.factor(year)1997:as.factor(target3)4	-0.397986	0.079622	-4.998	5.78e-07	***
as.factor(year)1998:as.factor(target3)4	-0.390850	0.078863	-4.956	7.19e-07	***
as.factor(year)1999:as.factor(target3)4	-0.384767	0.077954	-4.936	7.98e-07	***
as.factor(year)2000:as.factor(target3)4	-0.354341	0.076973	-4.603	4.16e-06	***
as.factor(year)2001:as.factor(target3)4	-0.314088	0.077530	-4.051	5.10e-05	***
as.factor(year)2002:as.factor(target3)4	-0.166896	0.081447	-2.049	0.040448	*
as.factor(year)2003:as.factor(target3)4	0.009485	0.082866	0.114	0.908876	
as.factor(year)2004:as.factor(target3)4	-0.323304	0.084091	-3.845	0.000121	***
as.factor(year)2005:as.factor(target3)4	-0.331480	0.086749	-3.821	0.000133	***
as.factor(year)2006:as.factor(target3)4	-0.143737	0.087205	-1.648	0.099297	.
as.factor(year)2007:as.factor(target3)4	-0.543139	0.083344	-6.517	7.18e-11	***
as.factor(year)2008:as.factor(target3)4	-0.202420	0.088724	-2.281	0.022521	*
as.factor(year)2009:as.factor(target3)4	-0.618762	0.092350	-6.700	2.08e-11	***
as.factor(year)2010:as.factor(target3)4	-0.545017	0.096484	-5.649	1.62e-08	***

as.factor(year)1995:as.factor(target3)5	-0.004947	0.077804	-0.064	0.949301	
as.factor(year)1996:as.factor(target3)5	-0.474150	0.077258	-6.137	8.40e-10	***
as.factor(year)1997:as.factor(target3)5	-0.303150	0.079589	-3.809	0.000140	***
as.factor(year)1998:as.factor(target3)5	-0.474835	0.078565	-6.044	1.50e-09	***
as.factor(year)1999:as.factor(target3)5	-0.439887	0.080762	-5.447	5.13e-08	***
as.factor(year)2000:as.factor(target3)5	-0.534400	0.077183	-6.924	4.40e-12	***
as.factor(year)2001:as.factor(target3)5	-0.420649	0.077594	-5.421	5.92e-08	***
as.factor(year)2002:as.factor(target3)5	-0.430286	0.081326	-5.291	1.22e-07	***
as.factor(year)2003:as.factor(target3)5	-0.276284	0.082997	-3.329	0.000872	***
as.factor(year)2004:as.factor(target3)5	-0.430765	0.083845	-5.138	2.78e-07	***
as.factor(year)2005:as.factor(target3)5	-0.656489	0.086568	-7.584	3.36e-14	***
as.factor(year)2006:as.factor(target3)5	-0.832651	0.088114	-9.450	< 2e-16	***
as.factor(year)2007:as.factor(target3)5	-0.916762	0.083665	-10.958	< 2e-16	***
as.factor(year)2008:as.factor(target3)5	-0.691328	0.089790	-7.699	1.37e-14	***
as.factor(year)2009:as.factor(target3)5	-0.635438	0.092662	-6.858	7.00e-12	***
as.factor(year)2010:as.factor(target3)5	-0.512386	0.095324	-5.375	7.65e-08	***
as.factor(year)1995:as.factor(target3)6	-0.014630	0.077899	-0.188	0.851031	
as.factor(year)1996:as.factor(target3)6	-0.623342	0.077644	-8.028	9.89e-16	***
as.factor(year)1997:as.factor(target3)6	-0.431950	0.079717	-5.419	6.01e-08	***
as.factor(year)1998:as.factor(target3)6	-0.612026	0.078882	-7.759	8.58e-15	***
as.factor(year)1999:as.factor(target3)6	-0.658007	0.079182	-8.310	< 2e-16	***
as.factor(year)2000:as.factor(target3)6	-0.657138	0.077112	-8.522	< 2e-16	***
as.factor(year)2001:as.factor(target3)6	-0.623911	0.077585	-8.042	8.87e-16	***
as.factor(year)2002:as.factor(target3)6	-0.557574	0.081456	-6.845	7.64e-12	***
as.factor(year)2003:as.factor(target3)6	-0.378758	0.083130	-4.556	5.21e-06	***
as.factor(year)2004:as.factor(target3)6	-0.609587	0.084074	-7.251	4.15e-13	***
as.factor(year)2005:as.factor(target3)6	-0.971398	0.087107	-11.152	< 2e-16	***
as.factor(year)2006:as.factor(target3)6	-0.671268	0.088274	-7.604	2.86e-14	***
as.factor(year)2007:as.factor(target3)6	-0.872390	0.083593	-10.436	< 2e-16	***
as.factor(year)2008:as.factor(target3)6	-0.776293	0.089190	-8.704	< 2e-16	***
as.factor(year)2009:as.factor(target3)6	-0.548232	0.092079	-5.954	2.62e-09	***
as.factor(year)2010:as.factor(target3)6	-0.687483	0.096016	-7.160	8.06e-13	***
as.factor(year)1995:as.factor(target3)7	-0.041261	0.078089	-0.528	0.597237	
as.factor(year)1996:as.factor(target3)7	-0.484646	0.077758	-6.233	4.58e-10	***
as.factor(year)1997:as.factor(target3)7	-0.482758	0.079948	-6.038	1.56e-09	***
as.factor(year)1998:as.factor(target3)7	-0.522427	0.079182	-6.598	4.17e-11	***
as.factor(year)1999:as.factor(target3)7	-0.789333	0.079583	-9.918	< 2e-16	***
as.factor(year)2000:as.factor(target3)7	-0.616773	0.077879	-7.920	2.38e-15	***
as.factor(year)2001:as.factor(target3)7	-0.597267	0.078477	-7.611	2.73e-14	***
as.factor(year)2002:as.factor(target3)7	-0.691534	0.081851	-8.449	< 2e-16	***
as.factor(year)2003:as.factor(target3)7	-0.327335	0.083819	-3.905	9.41e-05	***
as.factor(year)2004:as.factor(target3)7	-0.627997	0.084682	-7.416	1.21e-13	***
as.factor(year)2005:as.factor(target3)7	-1.008845	0.087855	-11.483	< 2e-16	***
as.factor(year)2006:as.factor(target3)7	-0.914014	0.088767	-10.297	< 2e-16	***
as.factor(year)2007:as.factor(target3)7	-0.949553	0.084159	-11.283	< 2e-16	***
as.factor(year)2008:as.factor(target3)7	-0.801790	0.089739	-8.935	< 2e-16	***
as.factor(year)2009:as.factor(target3)7	-1.179414	0.093411	-12.626	< 2e-16	***
as.factor(year)2010:as.factor(target3)7	-0.601907	0.096284	-6.251	4.07e-10	***
as.factor(year)1995:as.factor(target3)8	-0.101367	0.078223	-1.296	0.195023	
as.factor(year)1996:as.factor(target3)8	-0.471400	0.077698	-6.067	1.30e-09	***
as.factor(year)1997:as.factor(target3)8	-0.581691	0.080157	-7.257	3.96e-13	***
as.factor(year)1998:as.factor(target3)8	-0.696201	0.079181	-8.793	< 2e-16	***
as.factor(year)1999:as.factor(target3)8	-0.714996	0.079209	-9.027	< 2e-16	***
as.factor(year)2000:as.factor(target3)8	-0.760425	0.077548	-9.806	< 2e-16	***
as.factor(year)2001:as.factor(target3)8	-0.609672	0.077970	-7.819	5.31e-15	***
as.factor(year)2002:as.factor(target3)8	-0.662713	0.081823	-8.099	5.52e-16	***
as.factor(year)2003:as.factor(target3)8	-0.449224	0.083736	-5.365	8.10e-08	***
as.factor(year)2004:as.factor(target3)8	-0.812950	0.084757	-9.592	< 2e-16	***
as.factor(year)2005:as.factor(target3)8	-1.202706	0.087581	-13.733	< 2e-16	***
as.factor(year)2006:as.factor(target3)8	-1.188449	0.088593	-13.415	< 2e-16	***
as.factor(year)2007:as.factor(target3)8	-1.000165	0.084638	-11.817	< 2e-16	***
as.factor(year)2008:as.factor(target3)8	-0.732873	0.089712	-8.169	3.11e-16	***
as.factor(year)2009:as.factor(target3)8	-1.035433	0.093332	-11.094	< 2e-16	***
as.factor(year)2010:as.factor(target3)8	-0.791663	0.097021	-8.160	3.36e-16	***
as.factor(year)1995:as.factor(target3)9	-0.175616	0.077842	-2.256	0.024066	*
as.factor(year)1996:as.factor(target3)9	-0.684510	0.077566	-8.825	< 2e-16	***
as.factor(year)1997:as.factor(target3)9	-0.730206	0.079827	-9.147	< 2e-16	***
as.factor(year)1998:as.factor(target3)9	-0.786444	0.078595	-10.006	< 2e-16	***
as.factor(year)1999:as.factor(target3)9	-0.893709	0.079443	-11.250	< 2e-16	***
as.factor(year)2000:as.factor(target3)9	-0.761796	0.076968	-9.898	< 2e-16	***

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as.factor(year)2001:as.factor(target3)9  -0.694779   0.077867  -8.923  < 2e-16 ***
as.factor(year)2002:as.factor(target3)9  -0.926819   0.081466 -11.377  < 2e-16 ***
as.factor(year)2003:as.factor(target3)9  -0.588684   0.083390  -7.059 1.67e-12 ***
as.factor(year)2004:as.factor(target3)9  -0.888782   0.084252 -10.549  < 2e-16 ***
as.factor(year)2005:as.factor(target3)9  -1.412089   0.087485 -16.141  < 2e-16 ***
as.factor(year)2006:as.factor(target3)9  -1.413409   0.088059 -16.051  < 2e-16 ***
as.factor(year)2007:as.factor(target3)9  -1.206791   0.083848 -14.393  < 2e-16 ***
as.factor(year)2008:as.factor(target3)9  -0.986446   0.089267 -11.051  < 2e-16 ***
as.factor(year)2009:as.factor(target3)9  -1.154951   0.092520 -12.483  < 2e-16 ***
as.factor(year)2010:as.factor(target3)9  -0.251018   0.095792  -2.620 0.008781 **
as.factor(year)1995:as.factor(target3)10 -0.204871   0.077983  -2.627 0.008611 **
as.factor(year)1996:as.factor(target3)10 -0.874534   0.077534 -11.279  < 2e-16 ***
as.factor(year)1997:as.factor(target3)10 -0.988683   0.079696 -12.406  < 2e-16 ***
as.factor(year)1998:as.factor(target3)10 -1.032492   0.079027 -13.065  < 2e-16 ***
as.factor(year)1999:as.factor(target3)10 -0.934433   0.079391 -11.770  < 2e-16 ***
as.factor(year)2000:as.factor(target3)10 -0.820096   0.077475 -10.585  < 2e-16 ***
as.factor(year)2001:as.factor(target3)10 -0.865471   0.077779 -11.127  < 2e-16 ***
as.factor(year)2002:as.factor(target3)10 -0.987809   0.082190 -12.019  < 2e-16 ***
as.factor(year)2003:as.factor(target3)10 -0.909295   0.083505 -10.889  < 2e-16 ***
as.factor(year)2004:as.factor(target3)10 -0.971965   0.085089 -11.423  < 2e-16 ***
as.factor(year)2005:as.factor(target3)10 -1.524781   0.087651 -17.396  < 2e-16 ***
as.factor(year)2006:as.factor(target3)10 -1.703236   0.089516 -19.027  < 2e-16 ***
as.factor(year)2007:as.factor(target3)10 -1.564699   0.084072 -18.611  < 2e-16 ***
as.factor(year)2008:as.factor(target3)10 -0.359116   0.089409  -4.017 5.91e-05 ***
as.factor(year)2009:as.factor(target3)10 -0.634055   0.093079  -6.812 9.62e-12 ***
as.factor(year)2010:as.factor(target3)10  0.235201   0.096547   2.436 0.014846 *
as.factor(qt)2:as.factor(target3)2       -0.157843   0.069830  -2.260 0.023797 *
as.factor(qt)3:as.factor(target3)2        0.051322   0.069376   0.740 0.459441
as.factor(qt)4:as.factor(target3)2       -0.016117   0.072209  -0.223 0.823381
as.factor(qt)2:as.factor(target3)3       -0.121505   0.063999  -1.899 0.057625 .
as.factor(qt)3:as.factor(target3)3        0.161058   0.064279   2.506 0.012224 *
as.factor(qt)4:as.factor(target3)3        0.167863   0.067328   2.493 0.012660 *
as.factor(qt)2:as.factor(target3)4       -0.293758   0.061790  -4.754 1.99e-06 ***
as.factor(qt)3:as.factor(target3)4        0.030034   0.062748   0.479 0.632189
as.factor(qt)4:as.factor(target3)4        0.158735   0.064193   2.473 0.013406 *
as.factor(qt)2:as.factor(target3)5       -0.387590   0.061773  -6.274 3.51e-10 ***
as.factor(qt)3:as.factor(target3)5        0.117691   0.063354   1.858 0.063217 .
as.factor(qt)4:as.factor(target3)5        0.351138   0.063277   5.549 2.87e-08 ***
as.factor(qt)2:as.factor(target3)6       -0.488932   0.061300  -7.976 1.51e-15 ***
as.factor(qt)3:as.factor(target3)6       -0.033160   0.064990  -0.510 0.609894
as.factor(qt)4:as.factor(target3)6        0.244174   0.062611   3.900 9.62e-05 ***
as.factor(qt)2:as.factor(target3)7       -0.569636   0.061835  -9.212  < 2e-16 ***
as.factor(qt)3:as.factor(target3)7       -0.042211   0.066525  -0.635 0.525746
as.factor(qt)4:as.factor(target3)7        0.419933   0.062233   6.748 1.50e-11 ***
as.factor(qt)2:as.factor(target3)8       -0.729966   0.061913 -11.790  < 2e-16 ***
as.factor(qt)3:as.factor(target3)8       -0.306646   0.067846  -4.520 6.19e-06 ***
as.factor(qt)4:as.factor(target3)8        0.468546   0.062197   7.533 4.95e-14 ***
as.factor(qt)2:as.factor(target3)9       -0.756327   0.062386 -12.123  < 2e-16 ***
as.factor(qt)3:as.factor(target3)9       -0.324570   0.068744  -4.721 2.34e-06 ***
as.factor(qt)4:as.factor(target3)9        0.548719   0.062011   8.849  < 2e-16 ***
as.factor(qt)2:as.factor(target3)10      -0.878300   0.065441 -13.421  < 2e-16 ***
as.factor(qt)3:as.factor(target3)10      -0.439153   0.068156  -6.443 1.17e-10 ***
as.factor(qt)4:as.factor(target3)10       0.570693   0.062000   9.205  < 2e-16 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(1.1628) family taken to be 1)

    Null deviance: 137345  on 82539  degrees of freedom
Residual deviance:  94140  on 82336  degrees of freedom
AIC: 878013

Number of Fisher Scoring iterations: 1


              Theta:  1.16275
          Std. Err.:  0.00536

 2 x log-likelihood:  -877603.45500
```

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

Response: blshrk
                             LR Chisq  Df Pr(>Chisq)
as.factor(year)                2549.3  16  < 2.2e-16 ***
as.factor(qt)                  5114.7   3  < 2.2e-16 ***
as.factor(area)                9567.0   3  < 2.2e-16 ***
as.factor(target3)              812.9   9  < 2.2e-16 ***
as.factor(gyogyoucode)           67.3   1  2.276e-16 ***
as.factor(year):as.factor(target3)  3156.3 144  < 2.2e-16 ***
as.factor(qt):as.factor(target3)    2218.7  27  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```