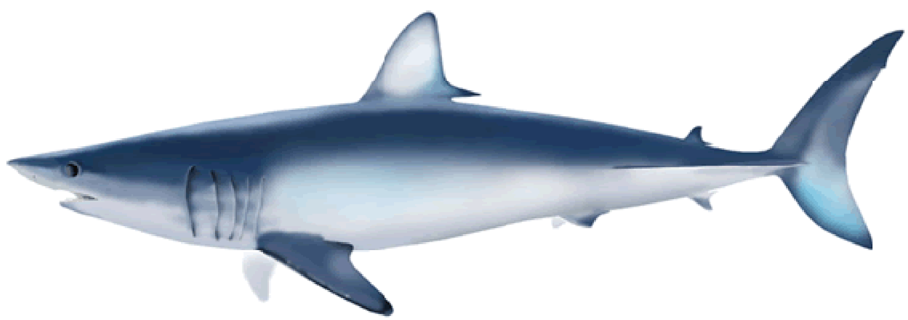
ISC/15/SHARKWG-1/01

Size and standardized CPUE of two pelagic sharks in the North Pacific based on salmon driftnet surveys[1]

Seiji Ohshimo, Ko Shiozaki and Kotaro Yokawa

National Research Institute of Far Seas Fisheries, Fishery Research Agency
5-7-1 Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN

Email: oshimo@affrc.go.jp



[1]Working document submitted to the ISC Shark Working Group Workshop, 9-17 March 2015, National Research Institute of Far Seas Fisheries, Shimizu, Shizuoka, Japan.

Abstract

Catch and effort data of two pelagic sharks, salmon shark and blue shark, caught in the salmon driftnet surveys conducted by Hokkaido University and Fisheries Research Agency in the period between 1978 and 2012 in the North Pacific Ocean, and were analyzed to investigate their distribution pattern in association with environmental factors such as sea surface temperature as well as their trend of population in the survey area. Likewise the catch composition of Japanese surface longliners in the offshore area of the northeastern Japan, blue shark is dominant in number in the subarctic-subtropical transition zone throughout the period analyzed. Salmon shark widely appears in the survey area including the Sea of Japan and the Bering Sea. Its standardized CPUE were apparently in the higher level in the period after the early 1990s, when high seas driftnet fishery is on moratorium, than in the 1980s.

Introduction

Two oceanic pelagic sharks such as salmon shark (*Lamna ditropis*) and blue shark (*Prionace glauca*) distribute widely in North Pacific Ocean, and play the roles of top predator in the marine ecosystem. These sharks, however, are popular in the catch of longline and driftnet fisheries, the detailed biological and ecological characteristics are poor as they mostly had been treated lightly by fishermen as bycatch with lower market values. Fishery independent data from appropriately designed surveys are prefered over fishery-dependent data because they do not have many of the biases associated with data from commercial or recreational fisheres due to change fish gear, methods and targeting practices over time (Simpfendorfer et al., 2002). The research surveys for estimating the abundance of salmon have been conducted in the North Pacific Ocean since early 1970s by Hokkaido University and Fisheries Research and blue shark and salmon shark were caungth as bycatch species in this survey. Therefore, the size and standardized CPUE of two sharks were analyzed.

Materials and Methods

Gears and sampling

The salmon driftnet surveys initiated in 1972 using both the research net designed for salmon and the commercial net used for catching salmon to examine the distribution pattern and approximate abundance of chum salmons and pink salmon in off Japan waters as well as to collect their biological information. Salmon driftnets have three types, and consisted of 30 tans (“tan” is a unit of net in Japanese, One tan of net is about 50 m in length and 7-10 m in depth) of net which were the combination of 10 kinds of geometric series mesh size nets from 48 to 157 mm to catch wide size range of fishes and other organisms, the commercial driftnets used 50 to 120 tans with 112-121 mm mesh size, and research driftnet used 1 to 40 tans with small mesh size (< 48 mm). The gear was set before sunset and retrieved around sun rise. Sites of salmon driftnet surveys were widely located in the 1970s and 1980s and thereafter survey areas shrunk through the 1990s and 2000s. Main survey months were June and July.

The date, position (latitude and longitude), number of tan used and number of catch by species were recorded for each operation. Sea surface temperature (sst) at the time of gear setting/retrieving were recorded, and sst at setting was used for CPUE standardization. The catch record of two sharks, salmon shark and blue shark are only available since 1978. Thus the salmon driftnet survey data in this study was used from 1978 to 2011. Body size (precaudal length; PCL cm) of each species was recorded on board at each operation site.

Data analyses and Modeling

The operation number, catch numbers of two sharks and tan were aggregated by year, latitude and longitude (1x1 resolution) was used. The sea surface temperature (sst) in each grid was averaged.

The standardized CPUE (number / tan) were computed by delta log-normal generalized linear model (GLM) The binomial part in delta model was as follows;

$r_y \sim \mathrm{Bin}(1, p_y)$

$\log(p/1\text{-}p) = \mathrm{factor(year)} + \mathrm{sst} + \alpha,$

where r_y is response variable on presence (=1) or absence (=0) of a catch, and p represents probability of the presence of a catch at stratum of year and sst, α is coefficient. The lognormal model part was as follows;

$\mathrm{lcpue} \sim N(\mu, \sigma^2)$

$\mu = \mathrm{factor(year)} + \mathrm{factor(gear)} + \mathrm{sst},$

where lcpue and gear represents log transformed CPUE (number/hooks), and gear types, respectively. The terminal data in the terminal year was eliminated by one year in order to evaluate the bias in the recent years. The terminal year changed from 1998 to 2011 in this analysis to see the effect of annual change of survey points on the historical trend of standardized CPUE.

Results

Total operation number was over 70,000 from 1978 to 2011, and the operation number and the total number of tan (equal to the amount of effort) drastically decreased in the period between the mid 1980s and the mid 1990s (Fig. 1). Total of 34 years of survey widely covered subtropical and temperate area in the northwest and the north central Pacific including the Sea of Japan, the Sea of Okhotsk as well as the Bering Sea from 33 degree north to 65 degree south (Fig. 2). Most of survey points located in the Pacific Ocean, and the lower and higher latitude was 33 and 65 degree, respectively. The main survey area was western side of north Pacific (west of date line).

Total catch number of salmon shark and blue shark for 34 years was 1,816 and 10,009, respectively, and the annual catch number of each species decreased as the decline of the amount of annual effort (Fig. 1). The main distribution area of two sharks was the Pacific Ocean, but relatively large number of salmon shark was also appeared in adjacent seas like the Sea of Japan and the Bering Sea.

Body length of blue shark decreased with latitude (high latitude), however there are no relationship between body length of blue shark and longitude (Fig. 3). Mean body length of salmon shark jumped from 180 cm to 80 cm at latitude 35 degree (Fig. 3), and there are no relationship between body length and longitude.

Standardized CPUE of (number/tan) salmon shark was low level in the 1980s, increased in the middle of 1990s and early 2000s, decreased after middle of 2000s. Standardized CPUE of blue shark in area 1 in the 1980s was stable at low level and drastically increased in the early 1990s, and after that, it was fluctuated but stayed in the higher level than that in the period before the mid 1990s (Fig. 4).

Discussion

The subarctic-subtropical transition zone, which is one of the main oceanic features in the North Pacific (Roden, 1991), provides important habitat for many epipelagic nekton species of fish, squid and shark that are highly migratory between subtropical areas and subarctic areas (Mishima, 1981; Kubodera et al., 1983), and have high productivity (Chai et al. 2003). This area is one of the important nursery grounds of pelagic sharks (Nakano and Nagasawa, 1996). Nakano and Nagasawa (1996) reported on the horizontal distribution of four pelagic shark species (salmon shark, blue shark, shortfin mako and spiny dogfish) using same data source as this study but the period of data was limited from 1981 to 1991. Japanese high-seas salmon fishery ceased in 1992 after approximately 40 years of industrial fishing from 1952 because of international concern for the impact of this fishery upon the oceanic ecosystem, and the salmon driftnet survey was continued even after the moratorium of the high seas salmon driftnet fishery to monitor the stock condition of chum and pink salmons and to collect their biological information as these two species were still rather important for Japanese coastal fisheries. Fisheries Agency and Fisheries Research Agency continued the salmon driftnet surveys since 1972 in the Pacific Ocean. Main target species was salmon therefore information of sharks of this surveys were not available in the first 6 years, and four sharks have been recorded since 1978. In the present study, standardized CPUEs based on delta log-normal GLM were calculated.

Nakano and Nagasawa (1996) reported that the most of salmon and blue sharks caught by the salmon driftnet survey was under 100cm in pre-caudal length. Unfortunately the size data did not collected after their study. Nakano et al. (1985) reported the sexual and size segregations of distribution of blue shark in the North Pacific, and blue shark was most abundant near subarctic boundary (approximately 37 to 43 degree N). The younger individuals were most common in the northern part of this area. In the present study, the smaller blue sharks were caught in the high latitude area (Fig. 3). For salmon shark, large difference of body length was observed at latitude 35 degree. In the northern part of survey area (> 36 degree latitude), most of salmon sharks were around 100 cm which were thought to be juveniles based on the reported growth formula (Goldman and Musick 2006). Therefore, the standardized CPUE indices of salmon shark and blue shark by the salmon driftnet surveys could be recognized to represent the abundances of recruitments. This should further be confirmed by collection of additional size data in the future. The results of retrospective analysis had positive effects on the historical trend of the standardized CPUE, but even considering this, the trend of the standardized CPUE of blue shark indicates that current level of juvenile of blue shark is in the historical average level.

Standardized CPUE of blue shark in this study also increased in the early 1990s (Fig. 3 upper). In WCPFC science committee noted there are substantial uncertainties in a number of inputs to the assessments, such as time spans of abundance indices (WCPFCSC 2014). Kai et al. (2014) reported that the abundance indices of blue shark in the North Pacific have increased since 1994 and peaked in the middle of 2000s, but those indices were segmented in 1994 and 2010. The standardized CPUE of blue shark estimated in this study seemed to have trend which is not contradict with the one reported by Kai et al. (2014) when the CPUE is considered as the abundance index of juvenile blue shark. Thus this blue shark CPUE is believed to bring rather useful information for the stock analysis of the north Pacific blue shark, especially in the point that it has longer time series than the indices used in the last stock assessment (ISC, 2014). The blue shark CPUE in this study was thought as one of long-term stock abundance of blue shark in the North Pacific, however the survey effort (total tan) drastically decreased, and uncertainty in the recent years would be large.

In our results, standardized CPUEs of both salmon and blue sharks increased since the early 1990s. The reasons of increases of salmon shark in the Bering Sea could be 1) warming the sea temperature or 2) banning the driftnet in the North Pacific in the early 1990s and the combinations of reason 1) and 2). In the Bering Sea, increase of the abundance of salmon shark during the 1990s was reported based on line-transect observation surveys by Okey et al (2007). They suggested the reasons of this increase were 1) declines in ocean mortality rates of Pacific salmon due to the moratorium of high seas salmon drift net fishery in 1991, 2) warming the sea temperature, 2) banning the driftnet in the early 1990s, 3) indirect fisheries effects such as competitive release of salmon sharks in the North Pacific transition and towards the more southern geographic extent of their annual migration as the result of fishery-related reductions in blue shark and other pelagic predators.

In this study, the standardized CPUE of salmon shark obtained by the fishery independent survey data covering wide range of distribution area of salmon shark. The trend of the CPUE in the 1990s was similar to that reported by in the previous study by Okey et al (2007) for the Bering Sea. These fact indicate that the trend of CPUE of salmon shark well represent the annual change of the level of its recruit. Collection of additional biological information such as sexed size data from this survey should contribute to the better understanding of the CPUE. They also indicated that other observations may help explain the CPUE increase of salmon shark, such as. Okey et al (2007) suggested that the reasons of the abundance increase in the Bering Sea were need to monitor the stock abundances of two sharks in the future.

References

Chai, F., Jiang, M., Barber R.T., Dugdale R. C., and Chao Y. (2003) Inter decadal variation of the transition zone chlorophyll front: a physical-biological model simulation between 1960 and 1990. J. Oceanogr., 59, 461-475.

Goldman K.J. and Musick J.A. (2006) Growth and maturity of salmon sharks (Lamna ditropis) in the eastern and western North Pacific, and comments on back-calculation methods. Fish. Bull., 104, 278-292.

Kai, M. Shiozaki, K., Ohshimo S., Yokawa, K., Takahashi N. and Kanaiwa M. (2014) Update of Japanese abundance indices and catch for blue shark Prionace glauca in the North Pacific. ICS/14/SHARKWG-1/02.

Kubodera, T., Pearcy, W.G., Murakami, K., Kobayashi, T., Nakata, J., Mishima, S., 1983. Distribution and abundance of squids caught in surface gillnets in the Subarctic Pacific, 1977-1981. Memoirs of the Faculty of Fisheries, Hokkaido University, 30, 1-49.

Mishima, S., 1981. On the passing over of subtropic fishes to the subarctic region in the summer season. Research Institute of North Pacific Fisheries (pp. 61-71). Hokkaido University Special Volume.

Nakano H. and Nagasawa K. (1996) Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. Fish. Sci., 62, 860-865.

Okey, T.A., Wright B.A. and Brubaker, M.Y. (2007) Salmon shark connections: North Pacific climate change, indirect fisheries effects, or just variability? Fish Fish., 1, 359-366.

Roden, G.I., 1991. Subarctic-subtropical transition zone of the North Pacific: large-scale aspects 622 and mesoscale structure. NOAA NMFS Tech Rep 105, 1-38.

Simppfendorfer, C.A., Hueter, R.E., Bergman, U., Connett, S.M.H. (2002) Results of a fishery-independent surveys for pelagic sharks in the western North Atlantic, 1977-1994. Fish. Res., 55, 175-192.

WCPFCSC (2014) Commission for the conservation and management of highly migratory fish

stocks in the western and central Pacific Ocean. pp. 192.

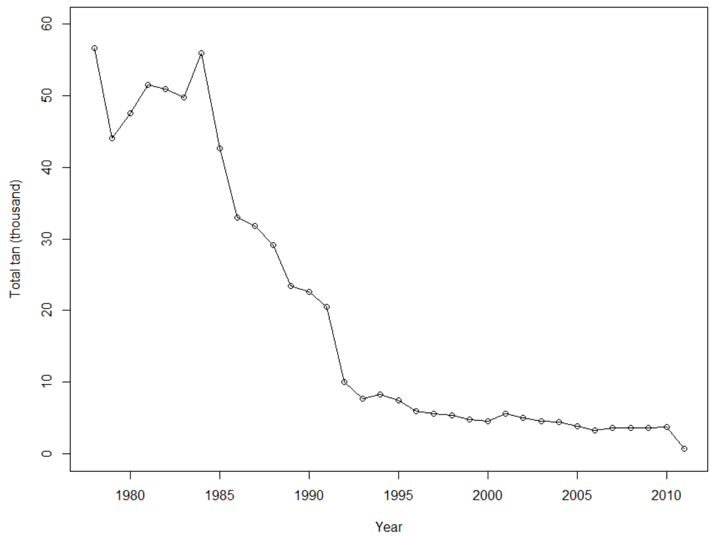


Fig. 1 Annual changes of total number of tan

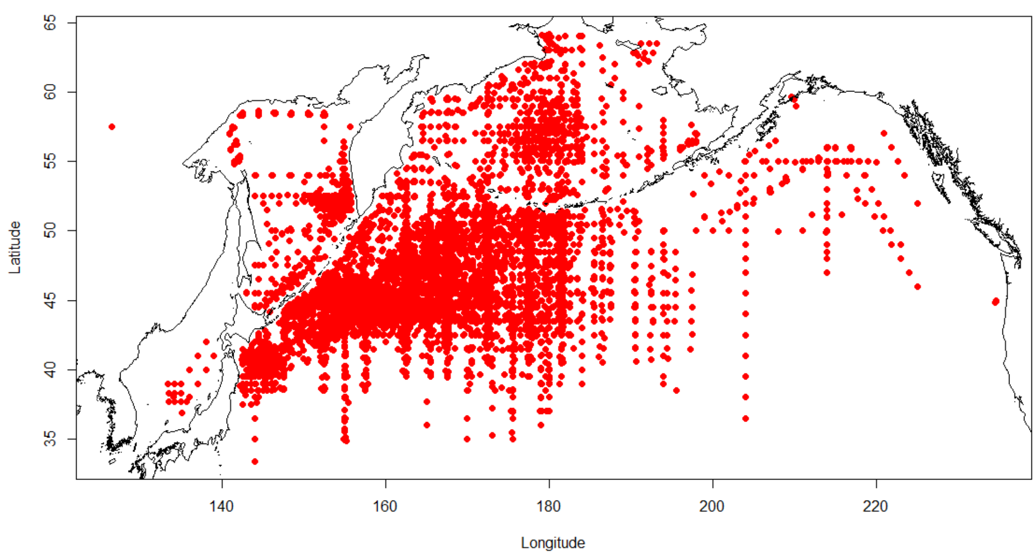


Fig. 2 Sampling sites of salmon driftnet from 1978 to 2011.

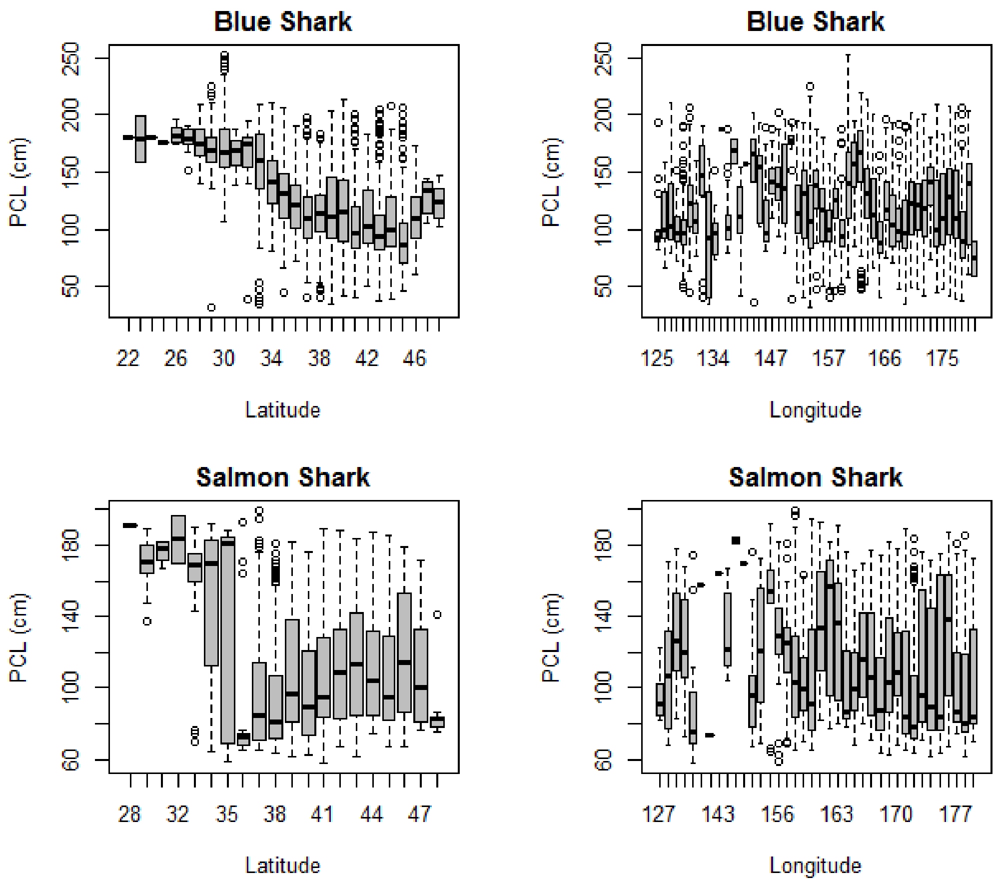


Fig. 3 Body length of blue shark by latitude (upper left) and by longitude (upper right), and salmon shark by latitude (lower left) and longitude (lower right). This results including the driftnet surveys of Pacific pomfret, and the surveys conducted from 1978 to 1984 and the locations were more southern area than salmon driftnet surveys.

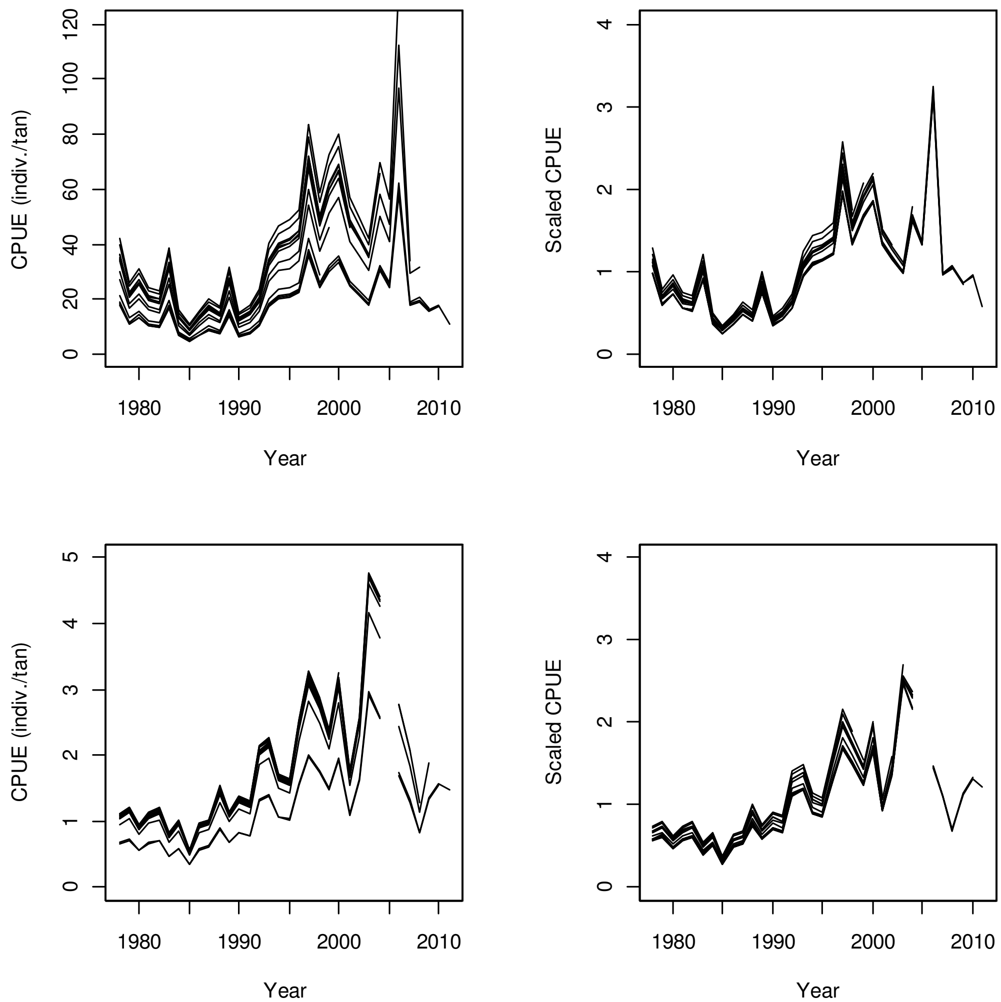
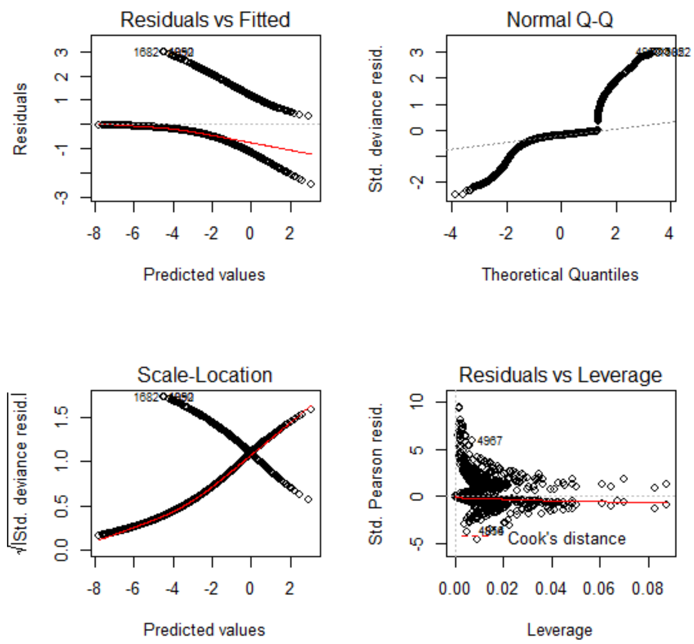


Fig. 4 Standardized CPUE and scaled CPUE of blue shark (upper left and right), and standardized CPUE and scaled CPUE of salmon shark (lower left and right) with 12 years of retrospective analysis.

Appendix

Blue shark



FigureA1 Diagnostics of the GLM analysis for salmon driftnet CPUE standardization of blue shark (binominal part).

Call:

```
glm(formula = p_bsh ~ as.factor(year) + sst, family = binomial,
    data = data3)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.4987	-0.2930	-0.1988	-0.1214	3.0027

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-8.05564	0.41730	-19.304	< 2e-16	***
as.factor(year)1977	0.83090	0.49168	1.690	0.091044	.
as.factor(year)1978	2.06424	0.43338	4.763	1.91e-06	***
as.factor(year)1979	2.62965	0.43279	6.076	1.23e-09	***

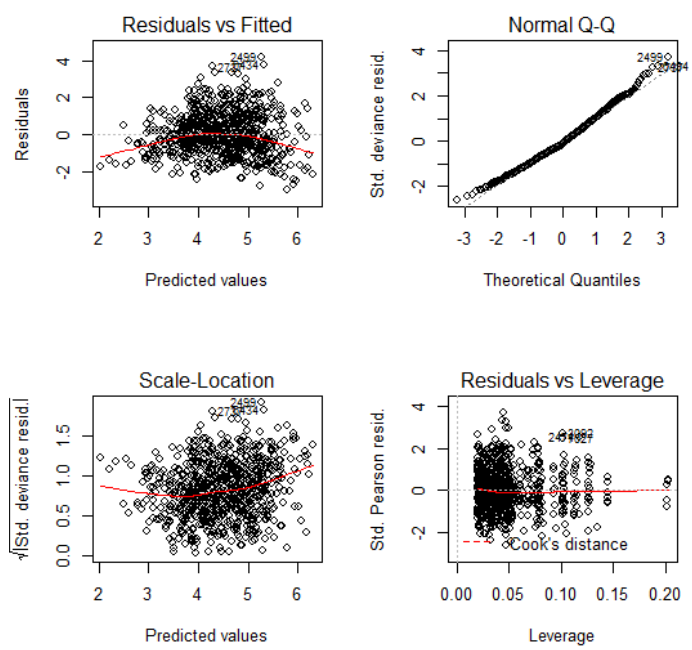
as.factor(year)1980	1.50532	0.47234	3.187	0.001438	**
as.factor(year)1981	1.30389	0.47023	2.773	0.005557	**
as.factor(year)1982	2.02186	0.43359	4.663	3.12e-06	***
as.factor(year)1983	1.68805	0.47043	3.588	0.000333	***
as.factor(year)1984	1.31469	0.45585	2.884	0.003926	**
as.factor(year)1985	1.88214	0.44836	4.198	2.69e-05	***
as.factor(year)1986	1.61228	0.45676	3.530	0.000416	***
as.factor(year)1987	1.66270	0.45104	3.686	0.000227	***
as.factor(year)1988	1.67343	0.46452	3.602	0.000315	***
as.factor(year)1989	1.36581	0.49069	2.783	0.005378	**
as.factor(year)1990	0.69967	0.49170	1.423	0.154747	
as.factor(year)1991	0.94376	0.47036	2.006	0.044809	*
as.factor(year)1992	1.36539	0.48495	2.816	0.004870	**
as.factor(year)1993	0.97413	0.49444	1.970	0.048818	*
as.factor(year)1994	0.71504	0.49641	1.440	0.149743	
as.factor(year)1995	1.82899	0.45936	3.982	6.85e-05	***
as.factor(year)1996	1.65700	0.47629	3.479	0.000503	***
as.factor(year)1997	1.19328	0.53499	2.230	0.025715	*
as.factor(year)1998	1.20180	0.59871	2.007	0.044718	*
as.factor(year)1999	2.12156	0.59039	3.594	0.000326	***
as.factor(year)2000	1.57383	0.64445	2.442	0.014601	*
as.factor(year)2001	1.67249	0.47454	3.524	0.000424	***
as.factor(year)2002	1.17999	0.47323	2.493	0.012650	*
as.factor(year)2003	-0.11779	0.54118	-0.218	0.827694	
as.factor(year)2004	0.01730	0.55687	0.031	0.975211	
as.factor(year)2005	0.84483	0.52911	1.597	0.110335	
as.factor(year)2006	-0.38685	0.60896	-0.635	0.525255	
as.factor(year)2007	-0.47962	0.58857	-0.815	0.415136	
as.factor(year)2008	-1.63890	0.58896	-2.783	0.005391	**
as.factor(year)2009	1.33647	0.60062	2.225	0.026072	*
as.factor(year)2010	-0.77004	0.57595	-1.337	0.181226	
as.factor(year)2011	1.75911	0.71936	2.445	0.014470	*
sst	0.38265	0.01135	33.725	< 2e-16	***

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

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 5388.2 on 8915 degrees of freedom
Residual deviance: 3424.2 on 8879 degrees of freedom
AIC: 3498.2

Number of Fisher Scoring iterations: 7



FigureA2 Diagnostics of the GLM analysis for salmon driftnet CPUE standardization of blue shark (positive catch part).

actor(year) + gear + sst, family = gaussian,
    data = data3[data3$blshrk > 0,])

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.9668	-0.7468	-0.1206	0.7411	4.1854

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	2.09674	0.46199	4.539	6.58e-06	***

factor(year)1977	-0.34619	0.54374	-0.637	0.5245
factor(year)1978	0.36401	0.47091	0.773	0.4398
factor(year)1979	-0.11863	0.47073	-0.252	0.8011
factor(year)1980	0.06492	0.50977	0.127	0.8987
factor(year)1981	-0.19114	0.50944	-0.375	0.7076
factor(year)1982	-0.24772	0.46972	-0.527	0.5981
factor(year)1983	0.29110	0.50933	0.572	0.5678
factor(year)1984	-0.59103	0.49925	-1.184	0.2369
factor(year)1985	-0.98816	0.48266	-2.047	0.0410 *
factor(year)1986	-0.61078	0.48773	-1.252	0.2108
factor(year)1987	-0.35375	0.48255	-0.733	0.4637
factor(year)1988	-0.52319	0.49335	-1.060	0.2893
factor(year)1989	0.10432	0.51288	0.203	0.8389
factor(year)1990	-0.64321	0.51669	-1.245	0.2136
factor(year)1991	-0.49028	0.49949	-0.982	0.3266
factor(year)1992	-0.19768	0.51605	-0.383	0.7018
factor(year)1993	0.33433	0.52831	0.633	0.5270
factor(year)1994	0.48192	0.50639	0.952	0.3416
factor(year)1995	0.52036	0.48900	1.064	0.2876
factor(year)1996	0.59037	0.50175	1.177	0.2397
factor(year)1997	1.06032	0.54984	1.928	0.0542 .
factor(year)1998	0.68645	0.57260	1.199	0.2310
factor(year)1999	0.90148	0.58557	1.539	0.1241
factor(year)2000	1.00768	0.60280	1.672	0.0950 .
factor(year)2001	0.68464	0.49402	1.386	0.1662
factor(year)2002	0.54691	0.50217	1.089	0.2765
factor(year)2003	0.38265	0.53734	0.712	0.4766
factor(year)2004	0.89150	0.59568	1.497	0.1349
factor(year)2005	0.68195	0.55163	1.236	0.2167
factor(year)2006	1.54694	0.60761	2.546	0.0111 *
factor(year)2007	0.35714	0.58123	0.614	0.5391
factor(year)2008	0.43609	0.57996	0.752	0.4523
factor(year)2009	0.22797	0.54500	0.418	0.6758
factor(year)2010	0.32522	0.56687	0.574	0.5663
factor(year)2011	-0.17383	0.68371	-0.254	0.7994
gearC	0.04717	0.09104	0.518	0.6045

gearF 0.23420 0.12598 1.859 0.0634 .

sst 0.14740 0.01473 10.008 < 2e-16 ***

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

(Dispersion parameter for gaussian family taken to be 1.341184)

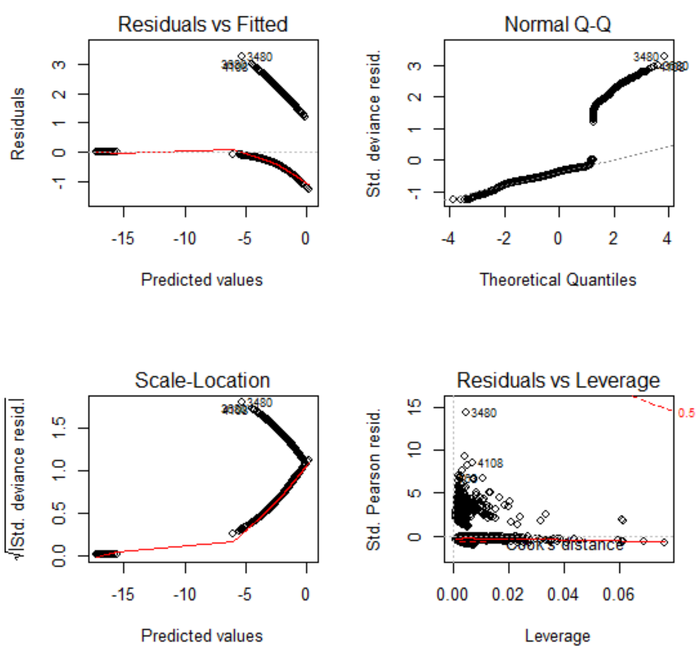
Null deviance: 1437.1 on 800 degrees of freedom

Residual deviance: 1022.0 on 762 degrees of freedom

AIC: 2548.3

Number of Fisher Scoring iterations: 2

Salmon shark



FigureA3 Diagnostics of the GLM analysis for salmon driftnet CPUE standardization of salmon shark (binominal part).

Call:

glm(formula = p_sal ~ as.factor(year) + sst, family = binomial,
    data = data3)

```
Deviance Residuals:
    Min        1Q    Median        3Q       Max
-1.2705   -0.5394   -0.3804   -0.2628    3.2669

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)         -2.416e+00  1.065e-01 -22.691  < 2e-16 ***
as.factor(year)1977 -7.775e-02  1.506e-01  -0.516 0.605688
as.factor(year)1978 -2.120e-01  1.513e-01  -1.402 0.160994
as.factor(year)1979  7.294e-04  1.560e-01   0.005 0.996270
as.factor(year)1980  7.913e-02  1.554e-01   0.509 0.610615
as.factor(year)1981 -3.176e-01  1.656e-01  -1.918 0.055168 .
as.factor(year)1982 -4.197e-01  1.587e-01  -2.645 0.008172 **
as.factor(year)1983 -1.193e+00  2.202e-01  -5.418 6.04e-08 ***
as.factor(year)1984 -1.043e+00  1.888e-01  -5.525 3.30e-08 ***
as.factor(year)1985 -9.235e-01  2.017e-01  -4.580 4.66e-06 ***
as.factor(year)1986 -1.852e+00  2.832e-01  -6.540 6.17e-11 ***
as.factor(year)1987 -1.648e+00  2.529e-01  -6.514 7.31e-11 ***
as.factor(year)1988 -1.796e+00  2.916e-01  -6.159 7.33e-10 ***
as.factor(year)1989 -1.683e+00  2.940e-01  -5.724 1.04e-08 ***
as.factor(year)1990 -2.181e+00  3.403e-01  -6.409 1.46e-10 ***
as.factor(year)1991 -1.451e+00  2.511e-01  -5.779 7.51e-09 ***
as.factor(year)1992 -1.955e+00  3.775e-01  -5.178 2.24e-07 ***
as.factor(year)1993 -2.447e+00  4.683e-01  -5.226 1.74e-07 ***
as.factor(year)1994 -1.778e+00  3.377e-01  -5.264 1.41e-07 ***
as.factor(year)1995 -1.795e+00  3.449e-01  -5.203 1.96e-07 ***
as.factor(year)1996 -1.367e+00  3.113e-01  -4.392 1.12e-05 ***
as.factor(year)1997 -1.110e+00  3.249e-01  -3.416 0.000635 ***
as.factor(year)1998 -9.486e-01  3.427e-01  -2.768 0.005639 **
as.factor(year)1999 -1.522e+00  5.289e-01  -2.878 0.004000 **
as.factor(year)2000 -1.756e+00  6.148e-01  -2.857 0.004277 **
as.factor(year)2001 -2.008e+00  4.093e-01  -4.906 9.27e-07 ***
as.factor(year)2002 -1.597e+00  3.374e-01  -4.733 2.21e-06 ***
as.factor(year)2003 -3.004e+00  6.020e-01  -4.990 6.05e-07 ***
as.factor(year)2004 -3.852e+00  1.012e+00  -3.804 0.000142 ***
```

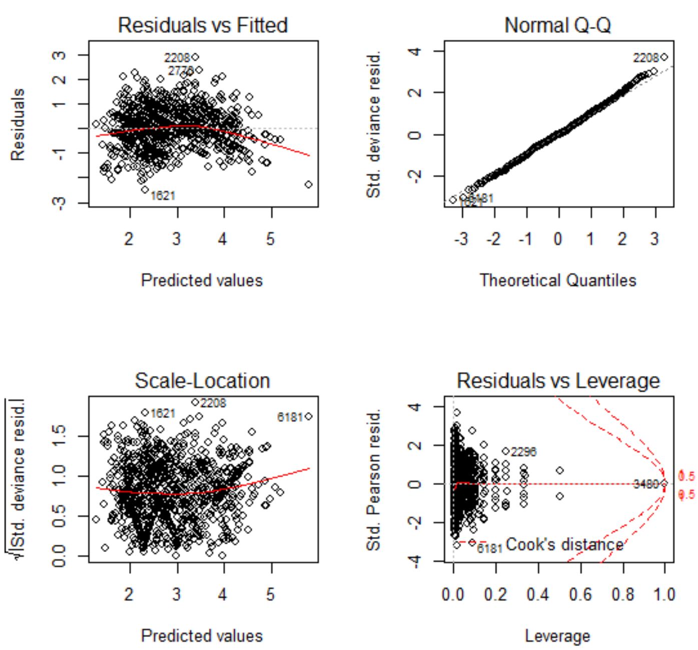
as.factor(year)2005 -1.569e+01 2.436e+02 -0.064 0.948630
as.factor(year)2006 -2.913e+00 7.336e-01 -3.971 7.16e-05 ***
as.factor(year)2007 -2.691e+00 6.100e-01 -4.412 1.03e-05 ***
as.factor(year)2008 -2.484e+00 4.917e-01 -5.051 4.38e-07 ***
as.factor(year)2009 -1.323e+00 4.305e-01 -3.074 0.002112 **
as.factor(year)2010 -1.172e+00 3.390e-01 -3.456 0.000548 ***
as.factor(year)2011 -4.104e-01 5.917e-01 -0.694 0.487925
sst 1.215e-01 8.720e-03 13.938 < 2e-16 ***

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

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 6079.1 on 8915 degrees of freedom
Residual deviance: 5550.3 on 8879 degrees of freedom
AIC: 5624.3

Number of Fisher Scoring iterations: 15



FigureA3 Diagnostics of the GLM analysis for salmon driftnet CPUE standardization of salmon shark (positive catch part).

```
Call:
glm(formula = log_sal ~ factor(year) + gear + sst, family = gaussian,
    data = data3[data3$salshrk > 0, ])

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.51280  -0.46646  -0.00772   0.48798   2.87721

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        0.988350   0.090525  10.918  < 2e-16 ***
factor(year)1977   0.070157   0.107465   0.653 0.514028
factor(year)1978   0.506565   0.108969   4.649 3.83e-06 ***
factor(year)1979   0.592406   0.112068   5.286 1.56e-07 ***
factor(year)1980   0.345998   0.110218   3.139 0.001748 **
factor(year)1981   0.509879   0.120825   4.220 2.69e-05 ***
factor(year)1982   0.584836   0.113900   5.135 3.45e-07 ***
factor(year)1983   0.212099   0.166172   1.276 0.202143
factor(year)1984   0.407022   0.141502   2.876 0.004115 **
factor(year)1985  -0.182432   0.149856  -1.217 0.223774
factor(year)1986   0.363668   0.215921   1.684 0.092470 .
factor(year)1987   0.399348   0.192928   2.070 0.038737 *
factor(year)1988   0.829852   0.221970   3.739 0.000197 ***
factor(year)1989   0.535831   0.222566   2.408 0.016258 *
factor(year)1990   0.738952   0.259537   2.847 0.004509 **
factor(year)1991   0.660311   0.187148   3.528 0.000439 ***
factor(year)1992   1.131511   0.291082   3.887 0.000109 ***
factor(year)1993   1.167184   0.363805   3.208 0.001382 **
factor(year)1994   0.894459   0.252488   3.543 0.000416 ***
factor(year)1995   0.839790   0.264810   3.171 0.001568 **
factor(year)1996   1.309767   0.232255   5.639 2.27e-08 ***
factor(year)1997   1.537139   0.241882   6.355 3.28e-10 ***
factor(year)1998   1.442774   0.249354   5.786 9.88e-09 ***
factor(year)1999   1.216089   0.405125   3.002 0.002757 **
factor(year)2000   1.579033   0.462474   3.414 0.000667 ***
```

factor(year)2001	0.934570	0.310160	3.013	0.002656	**
factor(year)2002	1.314999	0.252816	5.201	2.44e-07	***
factor(year)2003	1.957790	0.463507	4.224	2.64e-05	***
factor(year)2004	1.965779	0.794951	2.473	0.013585	*
factor(year)2006	1.431533	0.564838	2.534	0.011429	*
factor(year)2007	1.126486	0.463960	2.428	0.015374	*
factor(year)2008	0.582966	0.366761	1.589	0.112292	
factor(year)2009	1.134573	0.309887	3.661	0.000265	***
factor(year)2010	1.247195	0.236533	5.273	1.68e-07	***
factor(year)2011	1.178864	0.405318	2.908	0.003719	**
gearC	0.350419	0.063444	5.523	4.33e-08	***
gearF	0.797360	0.137987	5.779	1.03e-08	***
sst	0.131063	0.008671	15.116	< 2e-16	***

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

(Dispersion parameter for gaussian family taken to be 0.6276736)

    Null deviance: 1153.03 on 956 degrees of freedom
Residual deviance: 576.83 on 919 degrees of freedom
AIC: 2309.4

Number of Fisher Scoring iterations: 2