CPUE standardization of Pacific bluefin tuna from Korean offshore large purse seine fishery

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November 2019

Working document submitted to the ISC Pacific bluefin tuna Working Group, International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC), from 18 to 23 November 2019, La Jolla, CA, USA.

Introduction

Pacific bluefin tuna, *Thunnus orientalis* (PBF) has been caught by offshore large purse seine, set net, trawl, longline troll and others, and mostly by the offshore large purse seine fishery in Korean waters (Fig. 1). The main fishing ground of PBF of the offshore large purse seine fishery is around Jeju Island, however, it expands to the west to the Yellow Sea, north to coastal of Busan and east to the East Sea depending on PBF migration patterns by season (NFRDI, 2002; Yoon et al., 2012; Shin et al., 2018).

In this study, we conducted CPUE (catch per unit effort) standardization of PBF caught by the offshore large purse seine fishery using Generalized Linear Model (GLM) to assess the proxy of the abundance index.

Data and Methods

PBF data used for CPUE standardization in this study were obtained from Busan Cooperative Fish Market and Fisheries Cooperatives Radio Station, which contained vessel id, fishing date, location (latitude and longitude), time (day and night), effort (no. of hauls), and catch in weights of Pacific Bluefin tuna (PBF), common mackerel (CMK), common squid (CSQ), etc. (Fig. 3).

Data from the period 2004-2018 were used in the CPUE standardizations. Data prior to 2004 were not included in this study, as they have little information on catch and effort of PBF.

Data were plotted to explore the spatial and seasonal distributions of SBT catch through time.

To identify PBF target fishing, we applied cluster analysis of species composition to separate effort into groups that may have targeted PBF, and then included the categorical cluster variable in the standardization model (Hoyle et al., 2016). For this analysis we selected data that have PBF catch, and aggregated the data by vessel-month, and calculated proportional species composition by dividing the catch of each species by catch of all species in the vessel-month. The data were transformed by centering and scaling, to reduce the dominance of species with higher average catches. And we clustered the data using the hierarchical Ward hclust method and using the kmeans method

For the CPUE standardization, we used the lognormal constant GLM and delta lognormal analyses. Firstly, the lognormal constant GLM used is as follows.

$$\ln(CPUE_s + k) \sim yrqtr + latlong1 + cluster + \epsilon$$

The covariates were year-quarter (*yrqtr*), 1° cell (*latlong*1), and cluster (*cluster*) fitted as categorical variables.

Delta lognormal analyses (Lo et al. 1992, Maunder and Punt 2004) used a binomial distribution for the probability *w* of catch rate being zero and a probability distribution *f(y)* , where y was log(catch/hooks set), for non-zero (positive) catch rates. The index estimated for each year-quarter was the product of the year effects for the two model components, $(1-w).E(y|y \neq 0)$.

$$\Pr(Y = y) = \begin{cases} w, & y = 0 \\ (1-w)f(y) & otherwise \end{cases}$$

$g(w) = (CPUE = 0) \sim covariates + \epsilon$, where *g* is the logistic function.

$f(y) = CPUE \sim covariates + \epsilon$

Data in all models except the binomial model were 'area-weighted', with the weights of the sets adjusted so that the total weight per year-quarter in each 1° square would sum to 1. This method was based on the approach identified using simulation by Punsly (1987) and Campbell (2004), that for set *j* in area *i* and year-quarter *t*, the weighting function that gave the least average bias was: $w_{ijt} = \frac{log(h_{ijt}+1)}{\sum_{j=1}^{n} \log(h_{ijt}+1)}$. Given the relatively low variation in number of hooks between sets in a stratum, we simplified this to $w_{ijt} = \frac{h_{ijt}}{\sum_{j=1}^{n} h_{ijt}}$.

Results and Discussion

The nominal CPUE of PBF caught by offshore large purse seine fishery in Korean waters showed a decreasing trend in 2000s, but since 2012 it has shown an increasing trend except for 2015 and 2016 (Fig. 2).

The fishing areas of PBF by Korean offshore large purse seine fishery were mainly formed around Jeju Island, and widely expanded to the Yellow Sea and the East Sea (Figs. 4 and 5).

Applying Ward's D hierarchical cluster analysis at the vessel-month identified strong separation among 2 groups in PBF fishing area (Fig. 6). We chose to use two clusters in the CPUE standardization model. Clusters 1, and 2 were more strongly represented in the early, and late month, respectively (Fig. 7). Cluster 1 occurs largely in the period before June, while cluster 2 occurs largely in the period after June. Cluster 1 dominates the east, while cluster 2 dominates the west (Fig. 8). The species composition of cluster 2 comprises almost entirely common mackerel (CMK). Cluster 1 has lower common mackerel, while Pacific bluefin tuna and others are relatively higher (Fig. 9).

Fig. 10 shows the standardized year-quarterly CPUE trends of PBF with nominal CPUEs in relative scale. The standardized CPUEs had a large fluctuation, and are showing an increasing in 2017 and 2018. Diagnostic frequency distributions and QQ-plots (Fig. 11) suggest that the data fitted the GLM adequately.

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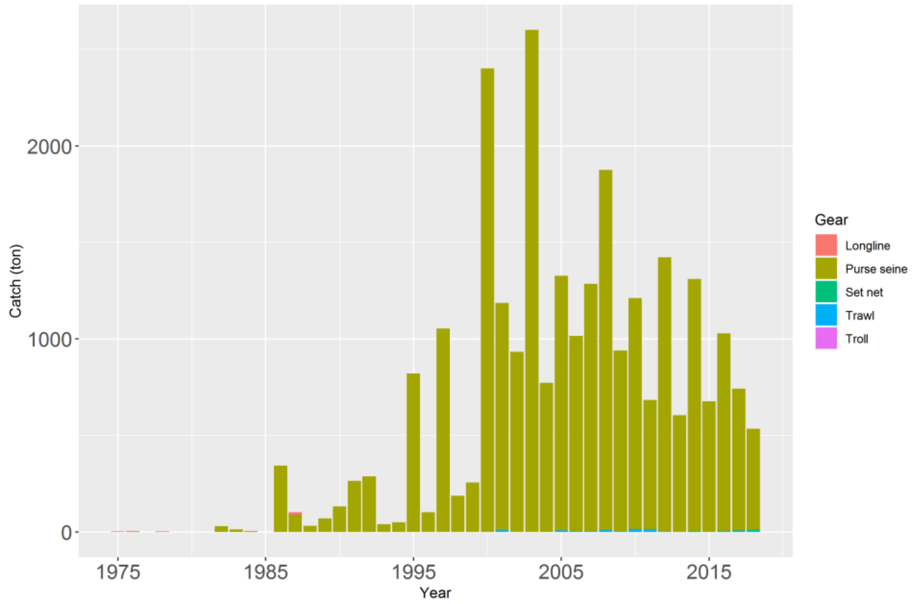

Fig. 1. Annual catch of PBF by fisheries in Korean waters, 1975-2018 (Data source: ISC database).

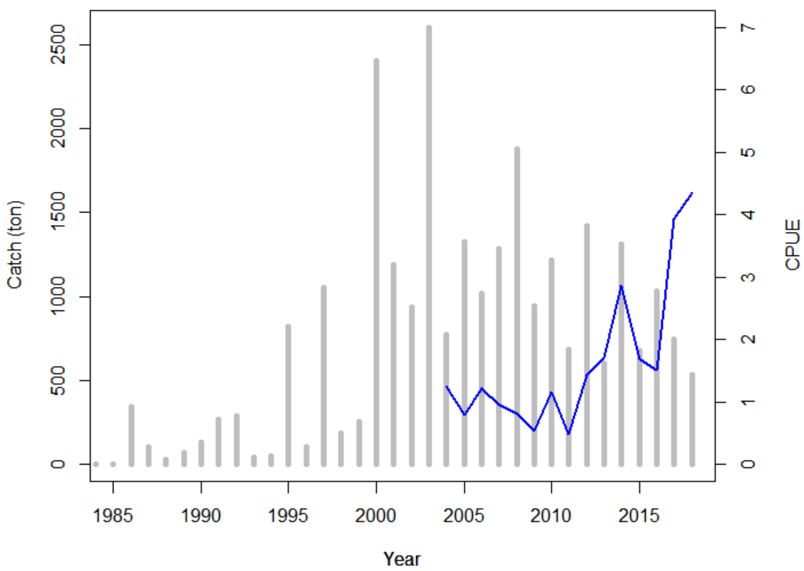

Fig. 2. Annual catch of PBF and its nominal CPUE caught by offshore large purse seine fishery in Korean waters, 1985-2018 (grey bar: catch, blue line: CPUE).

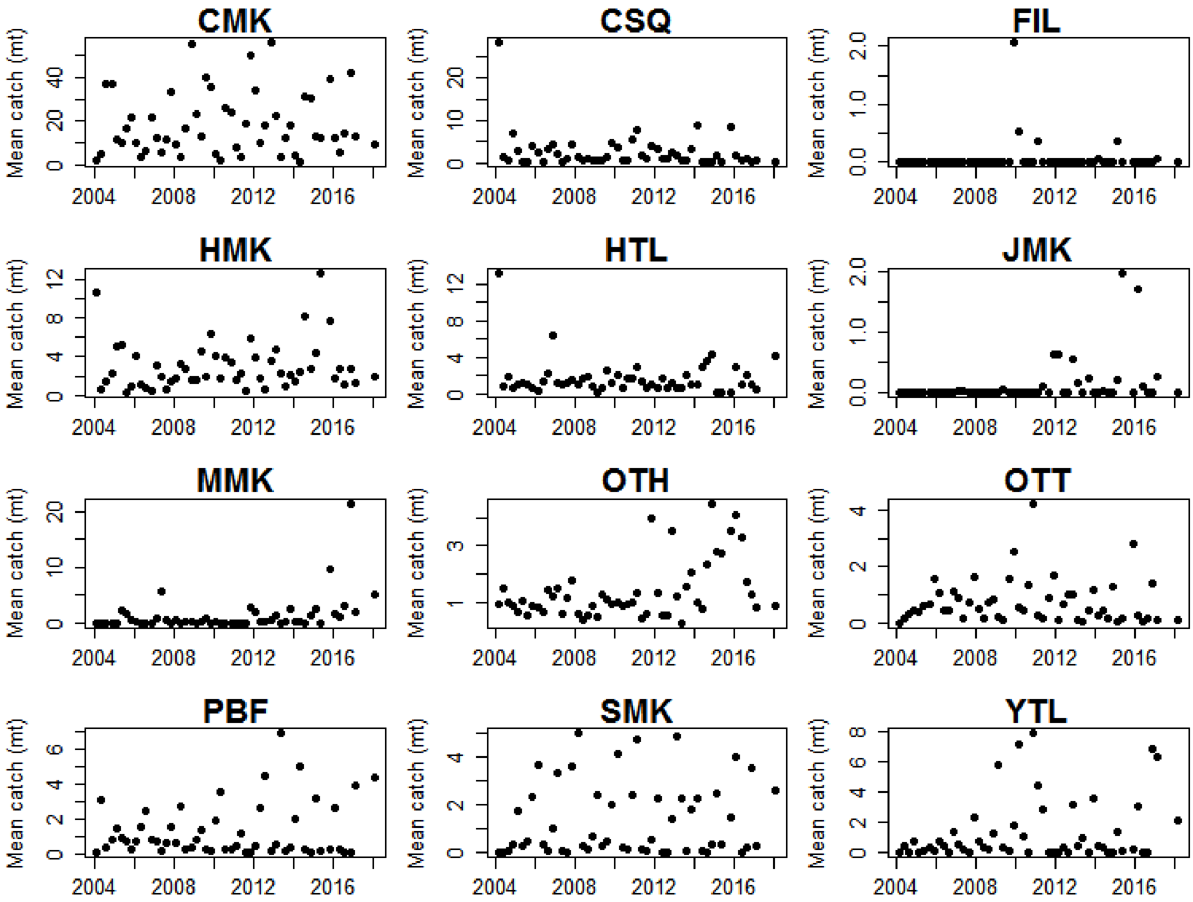

Fig. 3. Plots showing the mean catch per year of each species caught by offshore large purse seine fishery in Korean waters.

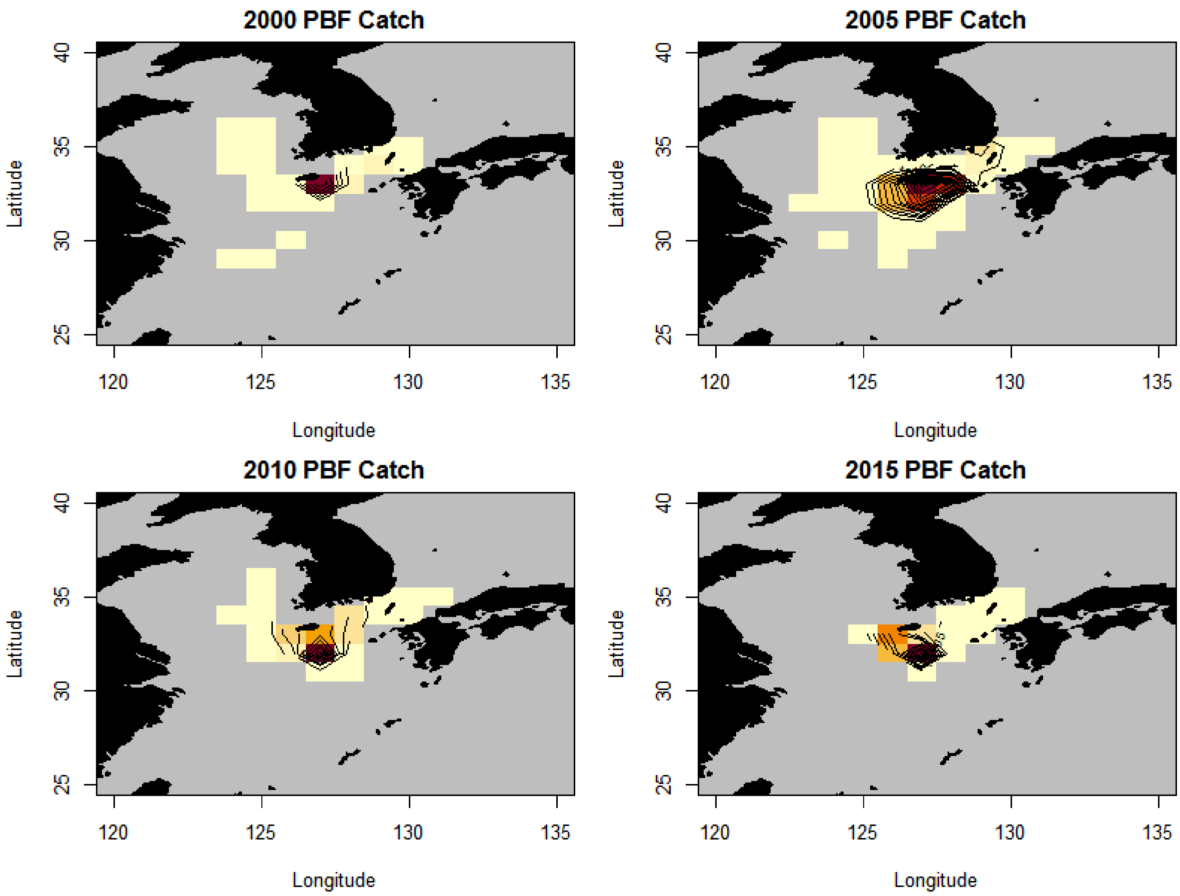

Fig. 4. Map showing the fishing areas of PBF of Korean offshore large purse seine fishery, aggregated by 5-year period. Red color indicates higher catch.

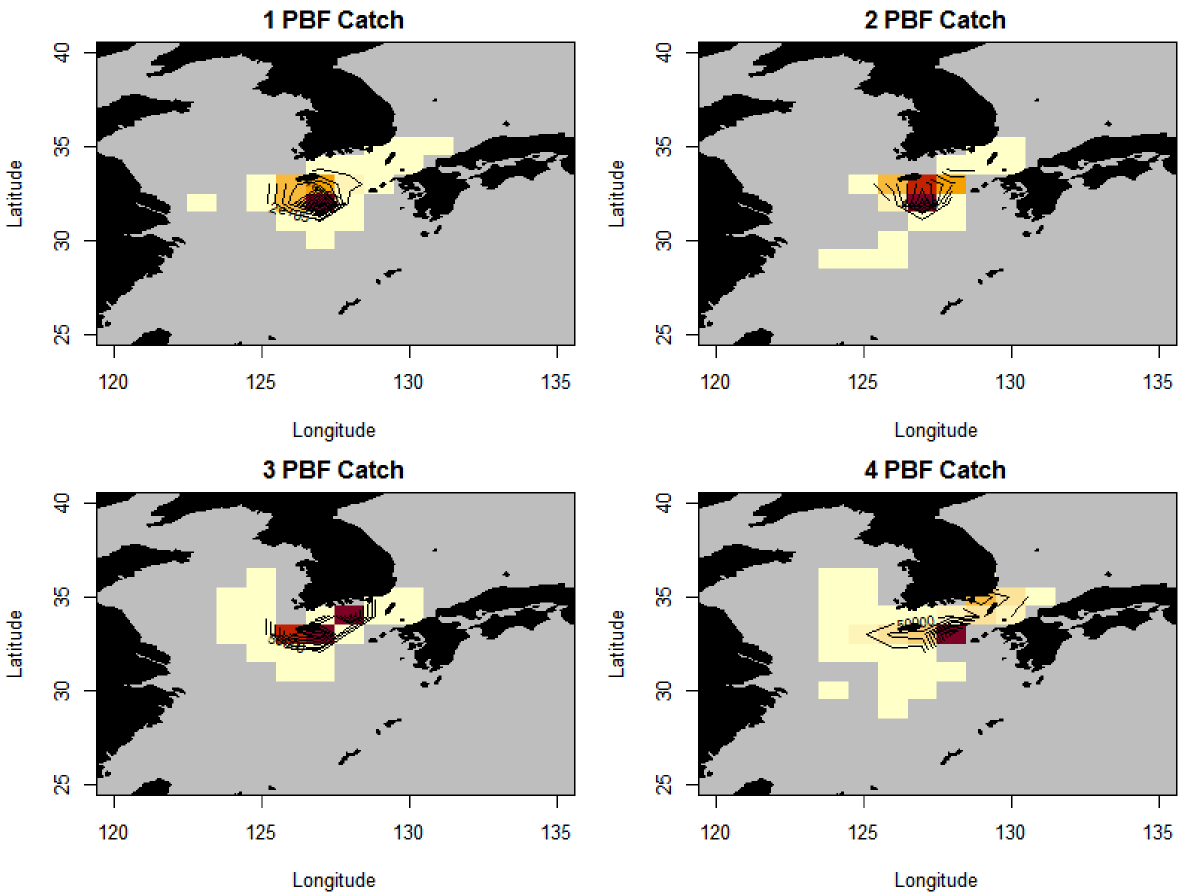

Fig. 5. Map showing the fishing areas of PBF of Korean offshore large purse seine fishery, aggregated by quarter. Red color indicates higher catch.

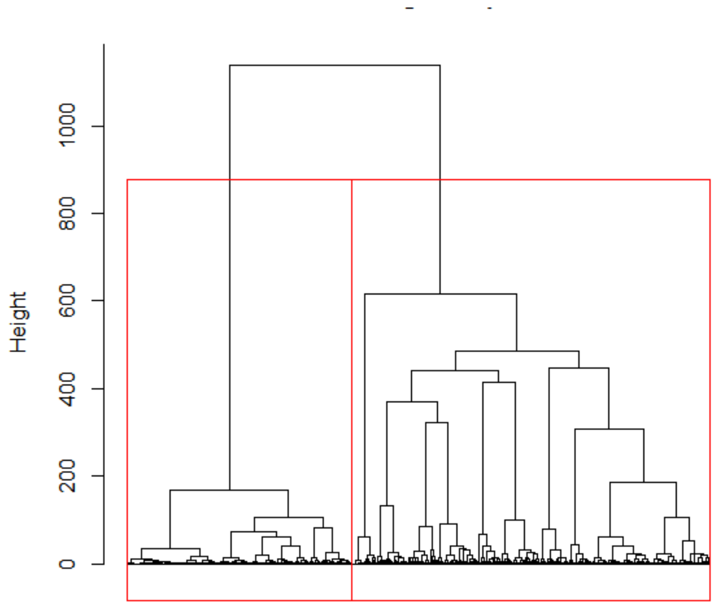

Fig. 6. Dendrograms for Ward hierarchical cluster analyses, with the red lines indicating the separation into 2 clusters.

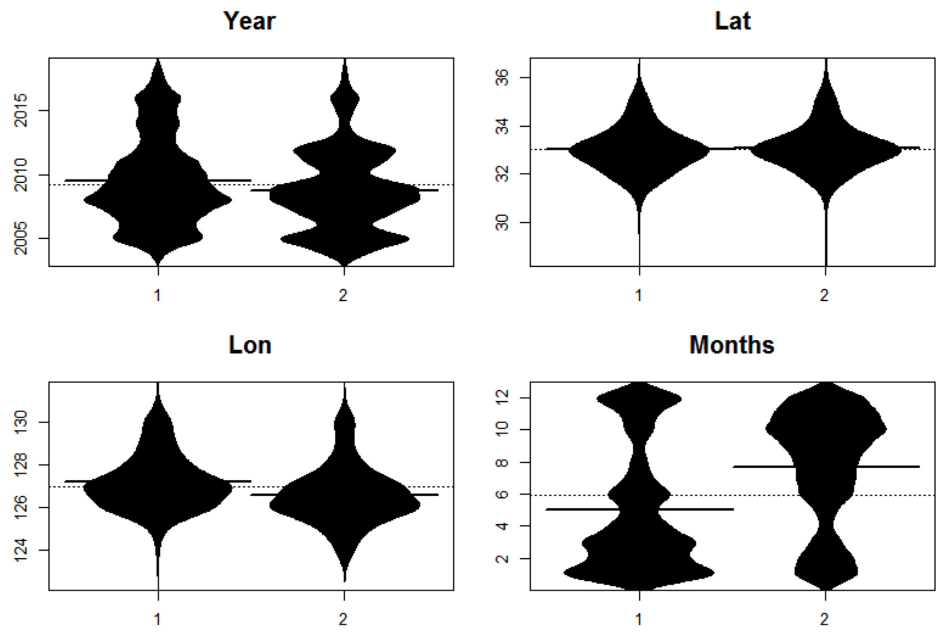

Fig. 7. Beanplots showing the number of sets versus covariate by cluster. The horizontal bars indicate the medians.

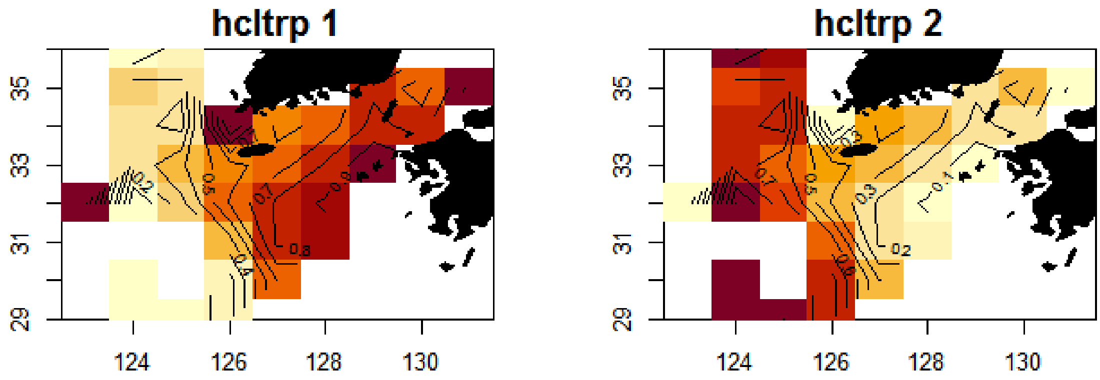

Fig. 8. Maps of the proportion of each cluster per 1 degree square in total effort. Higher proportions are shown in red.

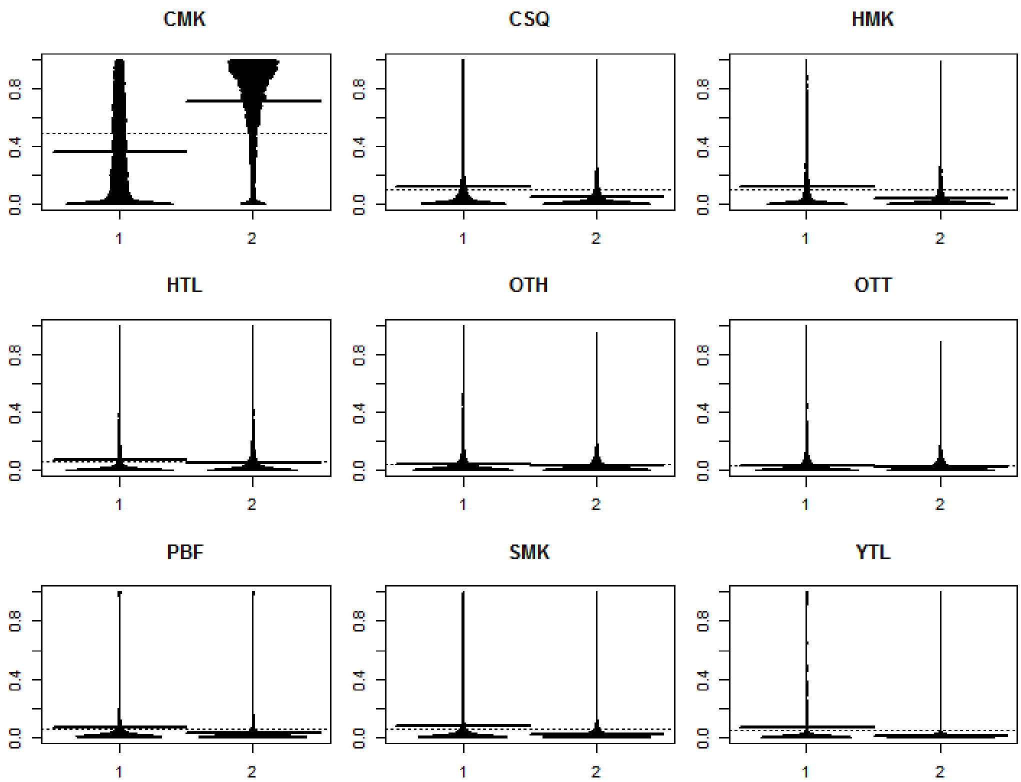

Fig. 9. Beanplots showing species composition by cluster. The horizontal bars indicate the medians.

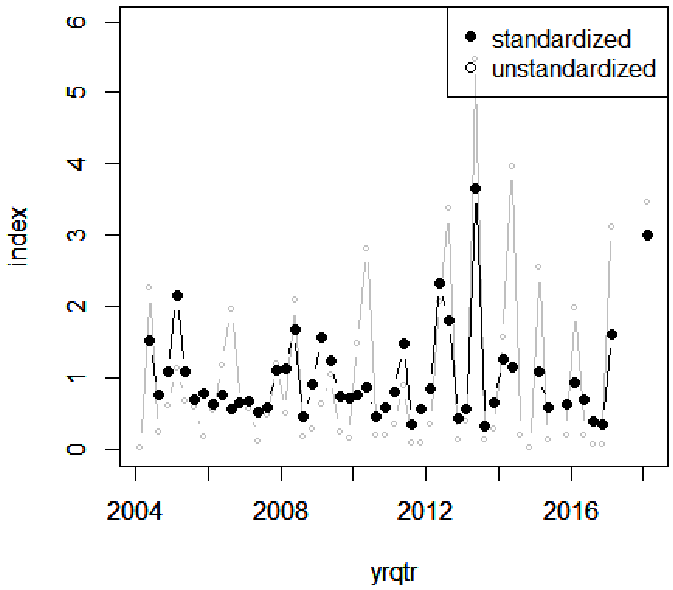

Fig. 10. The standardized quarterly PBF CPUE indices.

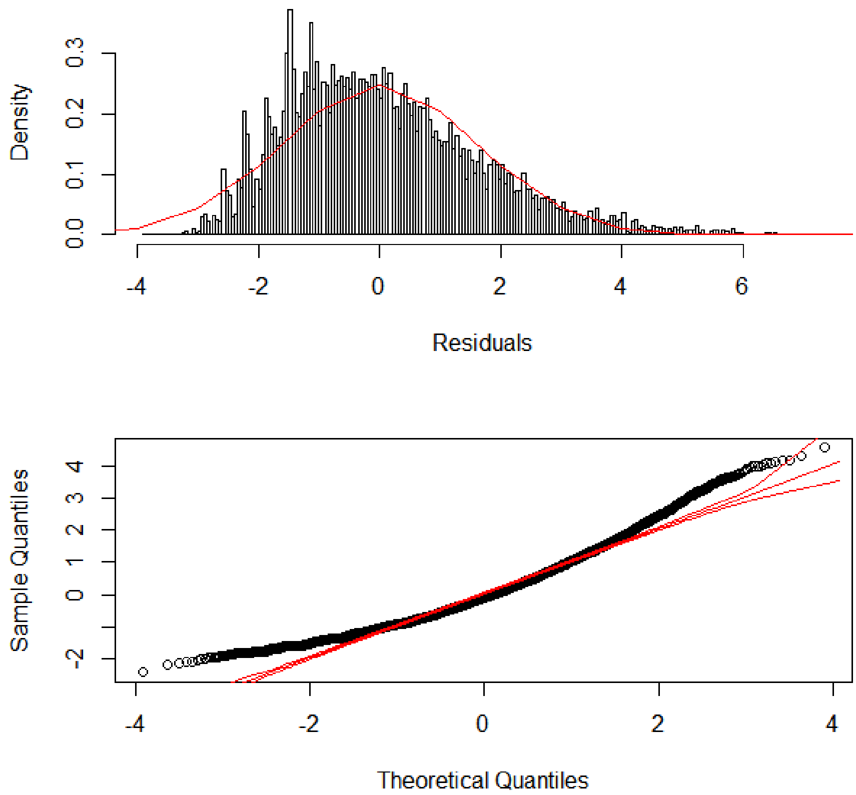

Fig. 11. Frequency distributions of the standardized residuals (upper) and Q-Q plots of standardized residuals (lower) for delta lognormal model.