CPUE standardization of black marlin (*Makaira indica*) caught by Taiwanese longline fishery in the Indian Ocean using targeting effect derived from principle component analyses

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ABSTRACT

In this study, the delta-lognormal GLM was used to conduct the CPUE standardization of black marlin (*Makaira indica*) caught by the Taiwanese longline fishery in the Indian Ocean for 1979-2015. CPUE trends were obviously different for northern and southern Indian Ocean, while the trend of area-aggregated CPUE series was similar to the CPUE series in the northern areas. The trend of area-aggregated CPUE indicated that high CPUEs occurred before late 1980s, substantially decreased and fluctuated in the 1990s, gradually declined from the late 1990s to 2005, and slightly increased in early years.

1. INTRODUCTION

Black marlin is considered to be a non-target species of industrial and artisanal fisheries. Gillnets account for around 59% of total catches in the Indian Ocean, followed by longlines (19%), with remaining catches recorded under troll and handlines. The catches were mainly made by Iran (gillnet, 24%), Sri Lanka (gillnet and fresh longline, 23%), India (gillnet and troll, 23%) and Indonesia (fresh longline and hand lines, 18%). In recent years, Taiwan has made only about 2% of total catches of black marlin in the Indian Ocean. Catches have increased steadily since the 1990s, from 2,800 t in 1991 to over 10,000 t since 2008. The highest catches were recorded in 2014, at nearly 18,000 t due to increases reported by the offshore gillnet fisheries of Iran. (IOTC, 2015).

Annual catches of black marlin caught by Taiwanese longline fishery were generally less than 1,000t and catch proportions were less 1-2% of total catches, except for the years before the early 1960s (Fig. 1). Fig. 2 shows the nominal CPUE distribution of black marlin of Taiwanese fleet. High CPUE generally occurred in the northern waters of 15S in the 1980s and 1990s, while high CPUEs were only observed in the waters around the Bay of Bengal.

Because black marlin was bycatch species of Taiwanese lognline fishery, large amount of zero-catches was recorded in the operational catch and effort data sets of Taiwanese longline fishery. The annual proportions of zero-catch were about 95% of total data sets. Therefore, the delta-lognormal GLM (Pennington, 1983; Lo et. al., 1992; Pennington, 1996) was applied to conduct CPUE standardization of black marlin in the Indian Ocean. The results of principle component analysis (PCA) based on the data sets in relation to species composition of the catches were also incorporated into CPUE standardization as an effect related to fishing operation (see Wang (2016) for the details).

2. MATERIALS AND METHODS

2.1. Catch and Effort data

In this study, daily operational catch and effort data (logbook) with 5x5 degree longitude and latitude grid for Taiwanese longline fishery during 1980-2015 were provided by Oversea Fisheries Development Council of Taiwan (OFDC). It should be noted that the data in 2015 is preliminary.

The data of number of hooks between float (NHBF) were available since 1994 and the collection of NHBF data were more complete since 1995. Therefore, the data of NHBF may not be applicable to conduct the long-term CPUE standardization for fishes caught by Taiwanese longline fishery in the Indian Ocean.

2.2. CPUE Standardization

A delta-lognormal GLM was applied to standardize the CPUE. The main effects considered in this analysis are year, month, area, and effects related to the fishing configurations (principal component scores, see Wang (2016) for the details). Fishing areas used in this study were defined by four areas based on the IOTC statistics areas for swordfish in the Indian Ocean (Fig. 3) (Wang and Nishida, 2011). Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. For the interaction associated with year effect, therefore, the interaction between year and area effect was only considered in models. The lognormal and delta models are conducted as follows:

Lognormal model for CPUE of positive catch:

$$\log(CPUE) = \mu + Y + M + A + T + \text{interactions} + \varepsilon^{\log}$$

Delta model for presence and absence of catch:

$$PA = \mu + Y + M + A + T + \text{interactions} + \varepsilon^{del}$$

where	*CPUE*	is the nominal CPUE of positive catch of black marlin (catch in number/1,000 hooks),
	PA	is the nominal presence and absence of catch,
	μ	is the intercept,
	Y	is the effect of year,
	M	is the effect of month,
	A	is the effect of fishing area,
	T	is the effect of targeting (principal component scores (PC_i) derived from the ith principle component),
	ε^{log}	is the error term, $\varepsilon^{log} \sim N(0, \sigma^2)$,
	ε^{del}	is the error term, $\varepsilon^{del} \sim Bin(n, p)$.

The model selection is based on the values of the coefficient of determination (R^2), Akaike information criterion (AIC) and Bayesian information criterion (BIC). The standardized CPUE are calculated based on the estimates of least square means of the interaction between the effects of year and area.

The area-specific standardized CPUE trends are estimated based on the exponentiations of the adjust means (least square means) of the interaction between year and area effects (Butterworth, 1996; Maunder and Punt, 2004).

The standardized relative abundance index is calculated by the product of the standardized CPUE of positive catches and the standardized probability of positive catches:

$$index = e^{\log(CPUE)} \times \left(\frac{e^{PA}}{1 + e^{PA}} \right)$$

2.3. Adjustment by area size

The estimation of annual nominal and standardized CPUE is calculated from the weighted average of the area indices (Punt et al., 2000).

$$U_y = \sum_a S_a U_{y,a}$$

Where U_y is CPUE for year y,
$U_{y,a}$ is CPUE for year y and area a,
S_a is the relative size of the area a to the four new areas.

The relative sizes of nine IOTC statistics areas for swordfish in the Indian Ocean (Nishida and Wang et al., 2006) were used to be aggregated into four areas used in this study.

Area	NW	NE	SW	SE
Relative area size	0.2478	0.2577	0.1638	0.3307

3. RESULTS AND DISCUSSION

Based on the model selections for the lognormal models incorporated *PCi* (principle component scores) as effects of targeting, all of main effects and interactions were statistically significant and remained in the models. The selected lognormal model was:

$$\begin{aligned}\log(CPUE) = \mu &+ Y + M + A + PC1 + PC2 + PC3 \\ &+ Y \times A + M \times A + M \times PC1 + M \times PC2 + M \times PC3 \\ &+ A \times PC1 + A \times PC2 + A \times PC3 + PC1 \times PC2 \\ &+ PC1 \times PC3 + PC2 \times PC3\end{aligned}$$

The ANOVA tables for selected lognormal models are shown in the Table 1. The results indicate that the main effects of *PC1* and *PC2* were the most explanatory main effect for the models and the secondarily explanatory main effect is the effect of year. In addition, interactions between area and *PC1* and between *PC1* and *PC2* also provided significant contributions to explanation of variance. The residuals obviously concentrated around -0.1 to 0 and thus distribution did not fit to the assumption of normal distribution very well (Fig. 4).

Similarly, all of main effects and interactions were statistically significant and remained in the model for the delta model incorporated principle component scores (*PCi*). The selected delta model was:

$$\begin{aligned} PA = \mu + Y + M + A + PC1 + PC2 + PC3 \\ + Y \times A + M \times A + M \times PC1 + M \times PC2 + M \times PC3 \\ + A \times PC1 + A \times PC2 + A \times PC3 + PC1 \times PC2 \\ + PC1 \times PC3 + PC2 \times PC3 \end{aligned}$$

The ANOVA tables for selected delta models are shown in the Table 2. Except for the effect of year, the most explanatory main effect for the mode was the effect of *PC2*. For delta models, the explanatory abilities of *PC1* and *PC3* were relatively lower than other main effects, and this can be observed for the interactions.

The area-specific standardized CPUE are shown in Fig. 5. The trends of CPUE series in the northern areas (NW and NE) reveal similar trends and they substantially decreased in the late 1980s although CPUE in NW revealed an obvious peak in 1992. Also, the CPUE series in the southern areas (SW and SE) are similar and they revealed increasing trends with fluctuations between the early 1990s and the early 2000s, and substantially decreased thereafter. The trend of area-aggregated CPUE series is similar to the CPUE series in the northern areas and high CPUEs occurred before late 1980s, substantially decreased and fluctuated in the 1990s, gradually declined from the late 1990s to 2005, and slightly increased in early years (Fig. 6).

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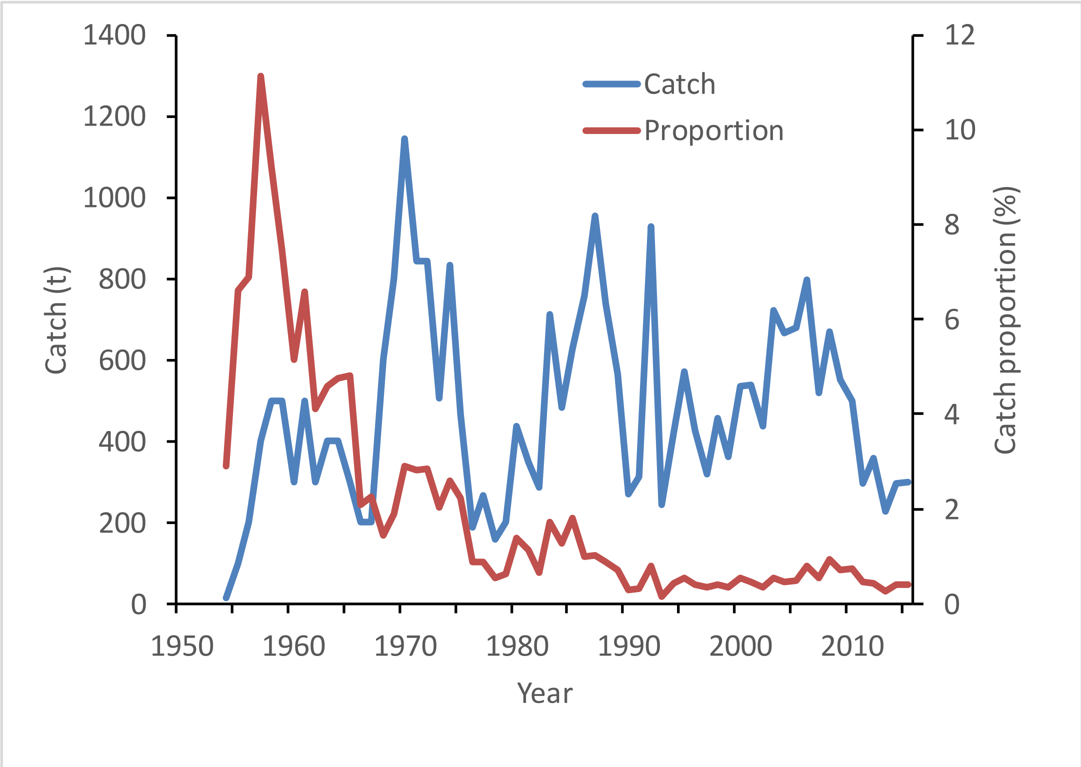

Fig. 1. Annual catch black marlin caught by Taiwanese longline fishery in the Indian Ocean.

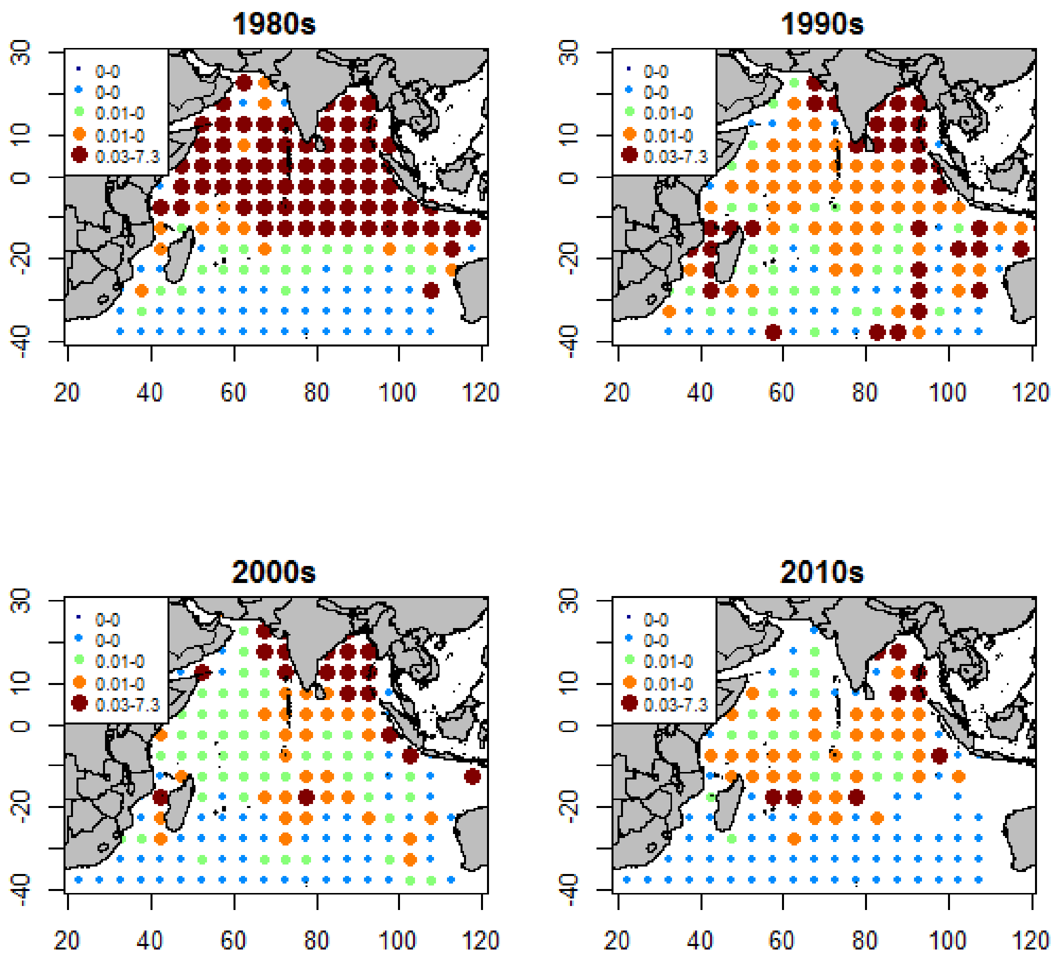

Fig. 2. Nominal CPUE distributions for black marlin caught by Taiwanese longline fishery in the Indian Ocean.

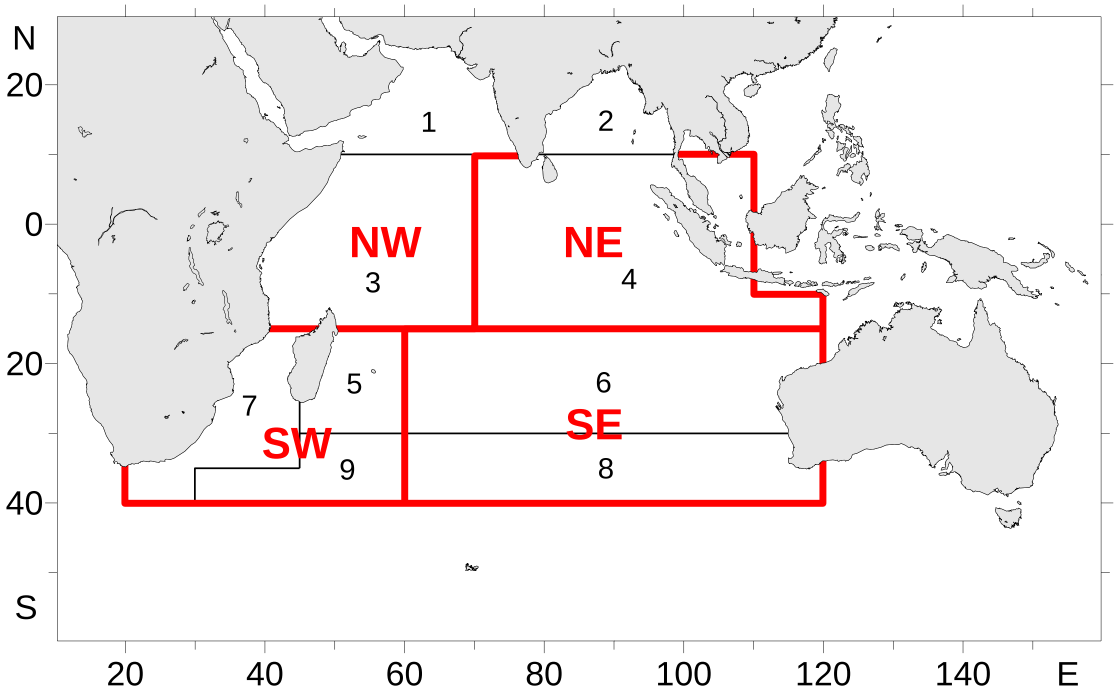

Fig. 3. Area stratification for swordfish in the Indian Ocean.

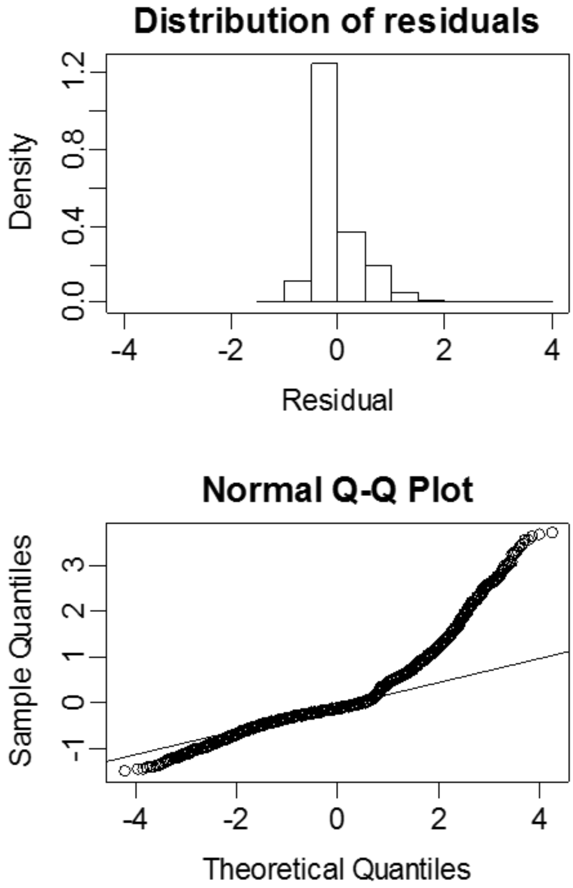

Fig. 4. The distributions and quantile-quantile plots of standardized residuals for lognormal and delta models incorporated principle component scores (PC_i) as effects of targeting.

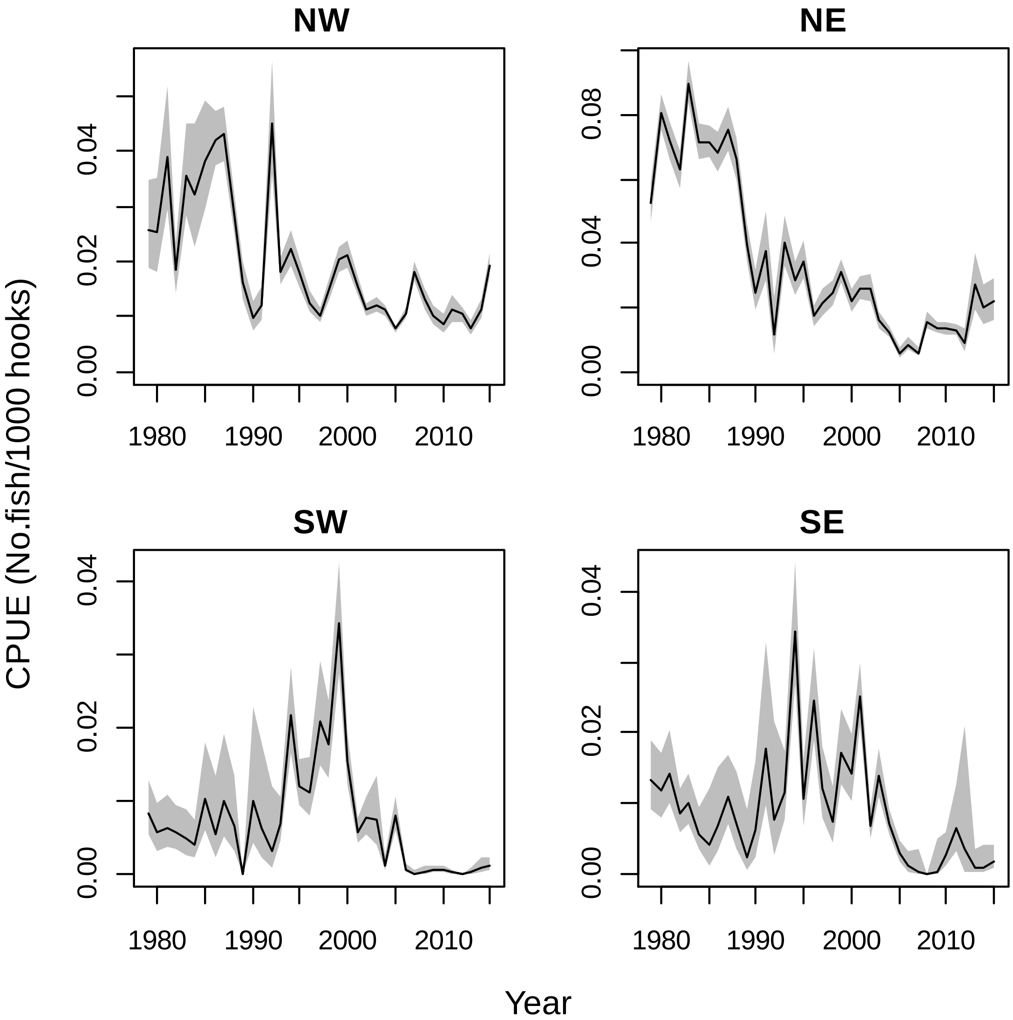

Fig. 5. Area-specific standardized (lines) CPUE with 95% confidence interval (shaded areas) for black marlin of Taiwanese longline fishery in the Indian Ocean. CPUEs were scaled by the averaged value for each series.

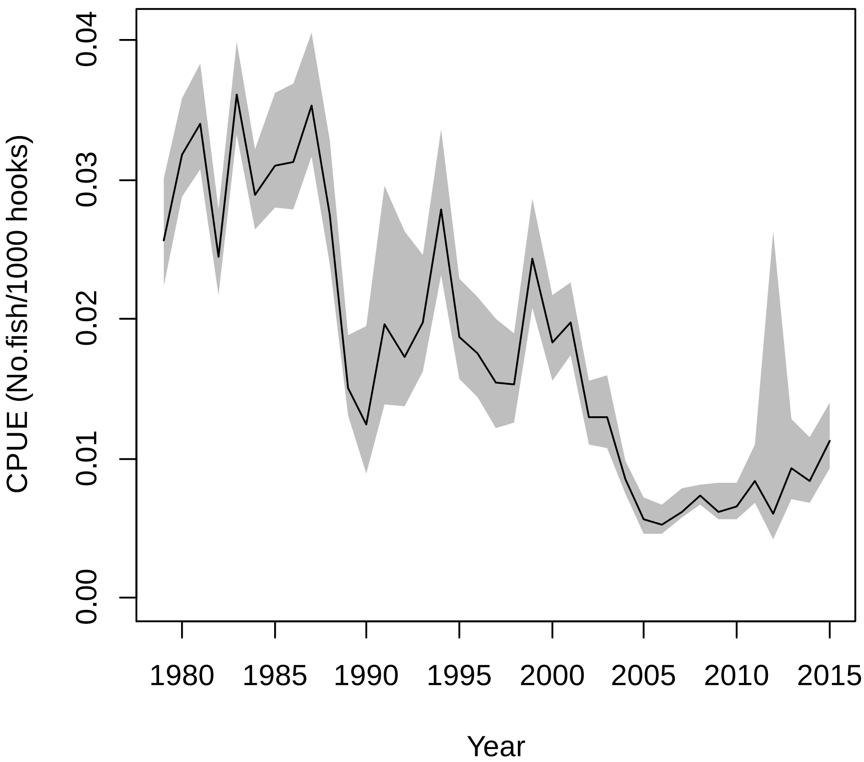

Fig. 6. Area-aggregated standardized (line) CPUE with 95% confidence interval (shaded area) for black marlin of Taiwanese longline fishery in the Indian Ocean. CPUEs were scaled by the averaged value for each series.

Table 1. The ANOVA tables for selected lognormal models incorporated principle component scores (*PC_i*) as effects of targeting.

Variables	Type III SS	Df	F	Pr(>F)
Y	180.4	36	23.5205	< 2.2e-16 ***
M	11.1	11	4.7526	2.45E-07 ***
A	6.5	3	10.1527	1.11E-06 ***
PC1	8.7	1	40.9619	1.57E-10 ***
PC2	8.3	1	39.0061	4.26E-10 ***
PC3	1.1	1	4.7541	0.029386 *
Y:A	257.6	105	11.5123	< 2.2e-16 ***
M:A	146.9	33	20.8866	< 2.2e-16 ***
M:PC1	20.5	11	8.7349	1.11E-15 ***
M:PC2	15.2	11	6.473	7.37E-11 ***
M:PC3	48.4	11	20.6298	< 2.2e-16 ***
A:PC1	53.8	3	84.2365	< 2.2e-16 ***
A:PC2	11.6	3	18.1761	8.79E-12 ***
A:PC3	15.4	3	24.0873	1.44E-15 ***
PC1:PC2	16.1	1	75.3331	< 2.2e-16 ***
PC1:PC3	2.7	1	12.8889	0.000331 ***
PC2:PC3	2.6	1	12.3072	0.000452 ***
Residuals	9712.7	45584		

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

Table 2. The ANOVA tables for selected delta models incorporated principle component scores (PC_i) as effects of targeting.

Variables	LR Chisq	Df	Pr(>Chisq)
Y	3959.6	36	< 2.2e-16 ***
M	142.1	11	< 2.2e-16 ***
A	180.4	3	< 2.2e-16 ***
PC1	4.9	1	0.026516 ***
PC2	887.7	1	< 2.2e-16 ***
PC3	12.1	1	0.000504 ***
Y:A	4012.8	108	< 2.2e-16 ***
M:A	1215.6	33	< 2.2e-16 ***
M:PC1	85.7	11	1.14E-13 ***
M:PC2	578.4	11	< 2.2e-16 ***
M:PC3	44.7	11	5.41E-06 ***
A:PC1	80.6	3	< 2.2e-16 ***
A:PC2	64.7	3	5.71E-14 ***
A:PC3	336.5	3	< 2.2e-16 ***
PC1:PC2	25.2	1	5.05E-07 ***
PC1:PC3	227.2	1	< 2.2e-16 ***
PC2:PC3	322.2	1	< 2.2e-16 ***

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