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CPUE estimation and factors influencing it from recreational angling of sockeye salmon (*Oncorhynchus nerka*), and management implications in Lake Toya, Japan

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Running title: Estimation and factors influencing CPUE

Abstract

Herein we examined the factors influencing catch per unit effort (CPUE), and standardized the CPUE of sockeye salmon *Oncorhynchus nerka* from offshore angling in Lake Toya, northern Japan. A generalized linear model (GLM) based on a negative binomial error distribution was used to standardize the catch and effort data collected from anglers using questionnaires and interview surveys during the fishing season (June) in 1998, 1999 and 2001–2012. Year, week, fishing area, number of fishing rods, fishing duration, and Year * Week were the factors that significantly (P <0.05) influenced CPUE. Anglers' fishing experience had no significant effect (P = 0.06) on CPUE. Limiting fishing duration, number of anglers and fishing rods may reduce fishing pressure and ensure sustainable management of the fishery. Our results on standardized CPUE can further be useful in fine–tuning age–based models such as Virtual Population Analysis (VPA–ADAPT) for the species in the lake, studies that are presently lacking. Regular and interdisciplinary studies that include biophysical factors are required to shed more light on the variations in abundance of the fish species in the lake and in the ecosystem at large.

Key words: CPUE, factors affecting CPUE, Lake Toya, recreational angling, sockeye salmon.

INTRODUCTION

Sockeye salmon *Oncorhynchus nerka* is the main target fish species in Lake Toya. The species is one of the most commercially important Pacific salmons (Morrow 1980). Sockeye salmon have been artificially introduced into many natural lakes and reservoirs in Japan since the end of nineteenth century for commercial fisheries (Shiraishi 1960; Tokui 1964). It was introduced into Lake Toya in the early twentieth century (Ohno & Ando 1932; Tokui 1964) and is now the dominant fish species in the lake (Sakano 1999). The species occurring in the lake has a lacustrine lifestyle (Kaeriyama 1991; Sakano *et al*. 1998). Thus for many generations, it has reproduced in the lake without oceanic migration. Lacustrine sockeye salmon has been added to the "red list" of threatened fishes of Japan (Ministry of the Environment 2007).

Recreational fishing is increasing rapidly in many coastal areas (Coleman *et al*. 2004), and developing countries (Cowx 2002; Freire 2005). For many years, recreational fishing was considered an ecologically friendly practice (Arlinghaus & Cooke 2009). However, it has recently been realized that recreational fisheries either contribute to the stock exploitation of the world fisheries (Cooke & Cowx 2004; Lewin *et al*. 2006; Granek *et al*. 2008) or hinder recovery in some areas (Coleman 2004). Recreational fishing is estimated to be responsible for about 12% of the worldwide catch for all fish (Cooke & Cowx 2006). Post *et al*. (2002) argued that for many freshwater systems, particularly small lakes and streams, recreational fishing has been the only source of fishing mortality and has led to the collapse of at least 4 high profile Canadian freshwater fisheries.

The most common source of fishery dependent data from recreational fisheries (or commercial fisheries) is catch and effort information expressed as catch per unit effort (CPUE). Given the lack of detailed information about the true nature of variables, a common situation in the majority of studies, CPUE is an assumed proxy for an index of fish stock abundance (Gulland 1964; Lima *et al*. 2000; Harley *et al*. 2001).

Factors other than fish abundance are known to affect CPUE (Walters 2003; Maunder *et al*. 2006). These factors include variation in catchability among different fishing vessels, gear and methods (Petrere *et al*. 2010). Also the ability of fishers to access the areas of greatest fish abundance interacts with habitat selection in fish (Harley *et al*. 2001), tow or fishing duration (Somerton *et al*. 2002; Fulanda & Ohtomi 2011). These factors confound the linearity between CPUE and abundance. Thus catchability (q) may vary spatially and temporally owing to changes in the composition of the fishing fleet, area and time (Cooke & Beddington 1984; Cooke 1985). Catchability is the fraction of the abundance that is captured by one unit of effort (Maunder & Punt 2004). Such factors preclude nominal CPUE from being used as an index of abundance (Beverton & Holt 1954; Harley *et al*. 2001).

For CPUE to be used as an index of abundance, the impacts of factors other than population abundance need to be removed (Gavaris 1980; Quinn & Deriso 1999). This process is known as catch–effort–standardization (Large 1992; Goñi *et al*. 1999; Punt *et al*. 2000). Thus standardized CPUE improves the proportionality of catch to the abundance as compared to nominal CPUE (Ye & Dennis 2009). For many years now, a number of methods and models have been used to standardize catch–effort data (Beverton & Holt 1954; Large 1992; Goñi *et al*. 1999; Maunder & Starr 2003; Maunder & Punt 2004; Song & Wu 2011). Generalized linear models (GLMs) are some of the models used to estimate coefficients of factors that influence CPUE (Hilborn & Walters 1992; Ye *at el*. 2001) and the standardization of abundance indices (Goñi *et al*. 1999; Maunder & Starr 2003). In fisheries science, GLMs are defined by the statistical distribution of the response variable (e.g. catch rate) and a link function that defines how the linear combination of a set of continuous variables relates to the expected value of the response (Maunder & Punt 2004). Under certain circumstances such as the nature of the data, and variation in spatial distribution of effort are likely to cause bias in standardized CPUE (Campbell 2004). Negative–binomial GLM is frequently used in ecology, including fisheries studies with zero inflated data to reduce overdispersion.

There are two categories of recreational fishing carried out in Lake Toya, onshore and offshore (Matsuishi *et al*. 2002). The latter category involves fishers who use boats as fishing vessels and is permitted for 5 months (June and December–March) each year. The average length and width of fishing boats is about 4 m and 1 m, respectively. Onshore angling, which does not use boats, is permitted for seven months, i.e. June–August and December–March. The month of June is generally recognized as the main fishing season on the lake, when anglers camp at landing sites or nearby to access the lake early in the morning. Fishing in both categories is permitted for 16 hours (from 4 in the morning to 7 in the evening). The maximum allowed number of both fishing rods and hooks per fishing rod is 3. Unlike the onshore anglers, offshore anglers in the lake sell the fish to retailers, hence commercially oriented.

Matsuishi *et al*. (2002) argued that offshore recreational angling has an impact on the population dynamics of sockeye salmon in Lake Toya. Recreational angling exploitation in the lake was estimated to have been 62% and 78% of the total harvest in 1998 and 1999, respectively. Commercial gillnet fishery accounted for the rest of the harvest. In addition, Hossain *et al*. (2010) reported that the adult sockeye population in the lake was at a low level of abundance. However, studies on sockeye salmon CPUE from recreational angling in the lake and the factors influencing it seem to be limited at present.

The main objectives of this study were to examine the factors influencing CPUE, and to standardize the CPUE index of sockeye salmon from offshore recreational angling by removing the impacts of these factors. The findings will be useful in further stock analysis, formulation of fisheries policies and management of the lake's resources at large.

MATERIALS AND METHODS

Description of the study area

Lake Toya is located between the cities of Sapporo and Hakodate in Hokkaido, northern Japan at 42° 36’ N and 140° 52’ E and an altitude of 84 m above sea level. It is an oligotrophic and largest caldera lake in Hokkaido with 10 and 2 rivers flowing into and out, respectively (Fig. 1). The lake has a surface area of 70.4 km^2, a shore length of 35.9 km and a maximum width of 9 km.

In this study, the lake was divided into 4 fishing sites namely A, B, C and D (Fig. 1). Area A has shallow water and an average depth of about 60 m (Ueda 2011). Area B has a slight sharp slope and its water depth ranges between 60 and 170 m. Areas C and D are on highly sloped beds in the deepest areas of the lake.

Data collection

Data were collected from offshore anglers at three landing sites, namely Takinoue, Tsukiura A and Tsukiura B (Fig.1) using interviews and questionnaires. Data were collected during June every year between 1998 and 2012 except for 2000 when the lake was closed to all activities due to a volcanic eruption.

Over the 14–years data collection period, a total of 6966 pre–fishing season questionnaires were distributed to anglers every year. Twenty four percent (n = 1695) of these questionnaires were returned (by mail) after the end of the fishing season. Additionally, 703 anglers were interviewed at the landing sites. The distributed questionnaires were filled out every day that an angler fished. A total of 4950 (703 and 4247 interviewed and distributed questionnaires) daily offshore angling data (cases) were collected and employed in our analysis.

The distributed questionnaires and that used for interviews contained the same questions. Distributions and interviews were performed in the same way as in Matsuishi *at el*. (2002). First, anglers were interviewed at landing sites (access point survey) after fishing. Second, questionnaires were distributed to anglers before the start of each fishing season. Anglers completed them and returned them by mail at the end of the fishing season (mail survey). Questionnaires were distributed to anglers in two ways. First, an angling association, *Choyukai* distributed the questionnaires (from the Lake Toya Fisheries Cooperative Association, LTFCA) to their members. Second, questionnaires were directly distributed to anglers at the landing sites. Anglers were requested to indicate their fishing license numbers on the questionnaires to avoid any duplication of data. The respondents provided information on the number of fish caught per day, fishing area, fishing duration (hours), number of anglers in their boats, number of fishing rods and hooks, angler's age (years) and angling experience (years).

Data analysis

Nine variables were used in the analysis. Three of these were treated as categorical factors: (1) year with 14 levels (1998, 1999 and 2001–2012), (2) week with 4 levels (4 weeks), and (3) fishing site with 4 levels (Area A–D). The continuous variables used comprised of fishing duration (hours), fishing experience of anglers (years), number of fishing rods and hooks, and number of anglers.

Anglers in the lake use fishing rod holders fixed on boats. This enables them to fish with a number of fishing rods at the same time, making it difficult to identify catches at the individual angler level from fishing boats with two or more anglers. Therefore, we calculated the average number of fishing rods, hooks and duration for each angler in a fishing boat. The same procedure was conducted both for anglers' ages and fishing experience.

Nominal CPUE was calculated as annual catch (number of fish) caught by a certain number of fishing rods per amount of time (hours) anglers spent fishing as shown in eq. 1.

$$CPUE_y = \frac{C_y}{R_y T_y} \quad (1)$$

where $CPUE_y$ is the catch per unit effort in year y, C_y is the total number of individual fish caught in year y, R_y is the total number of fishing rods used in year y, and T_y is the total number of hours spent by anglers in year y.

Before selecting the optimum model type for standardizing catch and effort, we checked three potential generalized linear models (GLMs) using Gaussian, Poisson and Negative–binomial distributions to see how well the datasets fitted. Before calibrating and selecting the best fitting model, Pearson product–moment correlation tests were conducted to identify potential continuous variables thought to influence CPUE. Only continuous variables that were not considered to be highly correlated were used in the models to avoid any possible collinearity occurring (Maunder & Punt 2004). Then, all the uncorrelated variables were fitted into the models. Different exploratory variables and interactions runs, particularly between year and other variables, were performed to check the sensitivity of the models (Rodríguez–Marín *et al*. 2003). Two–way random interactions between explanatory variables were used. All models failed to converge the Week * Area interaction hence this effect was not included in the simulations, and interactions between different variable effects were added separately (Campbell 2015).

For the model based on Gaussian distribution, CPUE was used as the response variable. The CPUE was calculated as catch by one angler per number of fishing rods per fishing duration (hours).

$$\ln(u+k) = Y + W + A + E + T + R + H + Y*W \quad (2)$$

where u is the daily CPUE (catch.angler^{-1}.rod^{-1}.hr^{-1}), k is the constant value (i.e. 10% of the average nominal CPUE), Y is the effect of year, W is the effect of a week, A is the effect of a fishing area, E is the effect of fishing experience, T is the effect of fishing duration, R is the effect of number of fishing rods, and H is the effect of number of hooks.

In the Poisson and negative binomial models, the catch (rounded to the nearest integer) per angler in a day (estimated from total catch divided by the number of angler in the boat) was used as the response variable. In the models, the response and independent variables were linked by log link function.

$$c = Y + W + A + E + T + R + H + Y * W \quad (3)$$

where c is the catch by one angler in a day.

Goodness–of–fit (or measure of dispersion) was calculated for the three models to select the model type that best fitted the data. Thus goodness–of–fit is a measure that was aimed at quantifying how well the GLMs used fitted the datasets. The goodness–of–fit was calculated as the ratio of residual deviance to degrees of freedom (Maydeu–Olivares & Garcı´a–Forero 2010), and the ratio should be about 1 to justify that there is no over dispersion.

In the next step, the stepwise function in R (R Development Core Team 2012) was used to determine the set of systematic factors and interactions that significantly explained the observed variability in the model (Rodríguez–Marín *et al*. 2003). This was followed by validation of the optimum model to examine whether the explanatory variables and interactions fitted to the model reduced variance in the data (Maunder & Punt 2004). We performed diagnostic tests on residuals versus predicted, and normal quantile–quantile (Q–Q) plot of standard deviance residuals versus theoretical values to compare the distribution of the data fitted by the optimum model to that of normal distribution.

Finally, we standardized the annual CPUE by multiplying the values of the explanatory variables by the parameter estimates from the model. The mean annual standardized CPUE was estimated based on the effects of the variables as follows:

$$\bar{U} = \exp\left[\mu + Y + \bar{W} + \bar{A} + \bar{E} + \bar{T} + \bar{R} + \bar{H} + \overline{Y} * \overline{W}\right] \text{ or } \bar{U} = \exp\left\lfloor \mu + Y \right\rfloor \text{ if } \bar{W}, \bar{A}, \ldots = 0 \qquad (4)$$

where $\overline{U}$ is the mean annual standardized CPUE, and μ is the intercept.

All data were analyzed using R software, version 2.15.0 for Windows (R Development Core Team 2012). All the statistical tests, particularly correlations, were assessed at 0.05 significance level.

RESULTS

Distribution and composition of fish catches

The observed mean catch was 8.87 ± 0.18 fish per angler per day. The angler's highest daily catch ranged from 1–5 individual fish (Fig. 2a). Catches of 1–10 comprised about 40% (*n* =1970) of the total catch for the whole duration of the study. Zero catch records for anglers comprised about 15% (*n* = 742) of all data used (Fig. 2b). The composition of zero catches were high in the in the beginning of the study with the highest record observed in 2003.

Annual trends of explanatory variables

Generally, the explanatory variables used in this study showed various trends between years. For instance, the total daily number of offshore anglers targeting sockeye salmon in the lake varied between years (Fig. 3a). High number of anglers was recorded in the first four years of the study i.e. 1998–2002, followed by a sharp decline in 2003. In the following eight years (2003–2010) the effort remained relatively low with annual fluctuations between years. The minimum fishing effort was recorded in 2005 (*n* = 93). Fishing effort increased in the last two years of the study i.e.

2011–2012. Generally, one fishing boat is used by one (Fig. 3b), thus a boat is rarely used by more than one angler although 2–3 anglers (constituting about 2–10% of anglers) were occasionally observed sharing one boat in the early years. The fishing experience of anglers in the lake also varied between years as indicated in Fig. 3c. The mean fishing duration has decrease in recent years (Fig 3d). Conversely, the average number of fishing rods used by anglers has increased since 2006 (Fig. 3e). The average annual number of fishing hooks per fishing rod used by one angler ranged from 1–4 (Fig. 3f). The highest numbers of fishhooks were recorded in 2005.

Correlations between continuous variables

The continuous variables showed low correlation coefficients between them. In other words, the variables were not highly correlated ($R < 0.5$) at the 5% significance level (Table 1). In the analysis, correlation between numbers of anglers in a boat and numbers of fishing rods was the highest ($R = -0.43$, $DF = 4948$, $P < 0.05$). Therefore, the former was not included as an explanatory variable in the standardization model. Though weak, the only positive significant relationship ($R = 0.26$, $DF = 4948$, $P < 0.05$) was found between the number of fishing rods and the number hooks used by anglers. The effect of hook number was not included in the final optimum model employed in the catch and effort standardization.

Measure of goodness of fit of models

Based on the measure of dispersion (Table 2), the binomial error distribution model i.e. negative–binomial generalized linear model (GLM) was considered to be the best model. Gaussian and Poisson models were not suitable for analyzing the datasets used in the current study. The negative–binomial GLM was preferred over the others primarily because it could handle the issue of overdispersion and the many zero catch data that occurred in some years of the study (Fig. 2).

Factors affecting CPUE

The result of analysis of deviance (ANOVA) for the optimum model is presented in Table 3. Year, week, area, age, fishing experience, duration and rod were the main explanatory factors found to influence CPUE (P <0.05). Additionally, the Year * Week interaction was also significant (P <0.05) ranking the second after year effect. The year effect on CPUE, varied significantly between years (Table 4) 2009 being the highest followed by 2007. The effect of these factors was lowest in 2002, 2003 and 2006. Additionally, the effect on CPUE decreased from the first week to the last week of June. It was evident that the greater the number of fishing rods used, and the longer the time an angler spent fishing the higher the effect on annual CPUE. Interestingly, fishing experience did not seem to have any direct significant effect on CPUE (Table 3 & 4). Additionally, the number of fishhooks used by anglers was shown to have no effect on annual CPUE.

Standardized CPUE trends

Figure 4 shows the annual trends of standardized CPUE. There were substantial differences in CPUE between adjacent years. The difference in magnitude of the upper and lower indices was high during the period of 1998–2004. The lowest and highest standardized CPUE was recorded during 2002–2003 and 2009, respectively.

Results of diagnostic tests

The plot of residuals versus predicted values showed that the model used for standardization reduced the variance of the continuous variables fitted. Additionally, a normal quantile–quantile (Q–Q) plot indicated that the data fitted to the model were normally distributed.

DISCUSSION

The current study is a preliminary attempt to standardize the catch per unit effort (CPUE) of sockeye salmon *Oncorhynchus nerka* caught by recreational anglers in Lake Toya. The research of Matsuishi *et al*. (2002) is the latest study on the population dynamics of sockeye salmon in the lake. However, the study was based on only two years' data and did not examine factors affecting catches that are herein studied. The present study is based on 14 years of datasets on offshore angling of sockeye salmon in the lake. Thus our work can be regarded as the baseline information on the causes of variation in CPUE.

Based on goodness–of–fit, the negative–binomial GLM was shown to robustly fit the data. The diagnostic plots (Fig. 5) indicated that the continuous variables that fitted the model had low variance, and that standard deviance residuals were normally distributed. This could suggest that the final model reasonably fitted the data and estimates (Pons *et al*. 2010). Zeroes in catch data might be the reason for the negative–binomial GLM model being preferred to other GLMs because it can handle dispersed data count (McCullagh & Nelder 1989).

It was evident that year, week in the fishing season and area were the categorical variables found to affect sockeye salmon CPUE in the lake. One of the reasons for decreases in CPUE during the fishing season could be high fishing pressure from offshore anglers. Matsuishi *et al*. (2002) reported that total exploitation rates were more than 60% of the species population during 1998 and 1999.

The number of fishing rods and fishing duration were shown to have a direct and significant influence on CPUE (Table 3). This suggested that the more time an angler spent fishing and the number of fishing rods they used, the more likely they were to catch more fish. This reflects the noticeable rise in CPUE due to an increase in the average number of fishing duration and rods (Fig. 3d & 3e). Furthermore, there was no strong correlation between hours spent fishing and catch. Thus it was incorrect to speculate that longer times spent fishing resulted in larger catches, and vice versa. Contrary to our expectation, fishing experience did not direct influence CPUE (Table 3 & 4). However, it was thought that fishing experience could have contributed to the selection of fishing sites. For instance, it was likely that experienced anglers in the lake fished more regularly in certain areas, particularly area D where the biggest river flows into the lake. The sockeye salmon use this, their natal river, for spawning (Ueda *et al*. 1998; Ueda 2011) hence requires conservation strategies such expansion of the area to protect the stock. Additionally, the effect of fishhook number was not selected in the final optimum model employed in the catch and effort standardization suggesting that it might be worthwhile to consider a existence of the relationship between the number of rods and hooks.

Maunder & Punt (2004) argued that interactions among factors occur frequently when standardizing catch and effort data. Year * Week effect may denote the existence of non–random effect(s) of the factors. Thus CPUE was not equally distributed between the weeks of the year. In other words, angling pressure was high in the beginning of fishing season and decreased from the first to the last week (Table 4). Therefore, not only fishing duration and number of fishing rods but also variation in the distribution of fish may have attributed to differences in CPUE between years. Any substantial fall in the number of anglers in one year resulted in an increase in CPUE in the following year. It has been reported that the total recreational impact on resources is more influenced by the number of anglers than individual catches per angler (Cooke & Cowx 2004). Limiting access to resources by anglers through reduction of the number of licenses will enhance awareness of resource management (Ruddle & Segi 2006; Martell *et al*. 2009).

The factors that influenced sockeye salmon CPUE, particularly the fishing areas, number of fishing rods used and fishing duration, can be useful in the policy formulation and management of the offshore angling in the lake. To ensure sustainability of the species and the lake’s ecosystem, we recommend enforcement of the currents regulations, and close monitoring of recreational fishery particularly offshore angling. One regulation that seems to go unenforced in the lake is limitation of fishing rods. We found that the average number of fishing rods per angler was about double of the permitted number of 3 fishing rods. We also advocate for expansion of the protected area adjacent to fishing area D that is a breeding ground for sockeye salmon to enhance reproduction and abundance of the stock. Also, fishing duration should be reduced from the permitted 16 hours to at least 10 hours. The current standardized abundance index will be be useful in further stock analysis, for instance in the fine–tuning age–based models such as Virtual Population Analysis (VPA–ADAPT) and other studies that are lacking in this lake. In addition, future studies should examine the effect of environmental and biological factors to shed more light on and improve our understanding of the species population dynamics and the ecosystem of the lake at large.

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List of figures legends

Fig. 1 Map of Lake Toya, Japan showing fishing areas and landing sites.

Fig. 2 (a) Distribution of observed catch per angler per day and (b) proportion (%) composition of zero and positive (non–zero) catches of sockeye salmon from recreational angling in Lake Toya, Japan during 1998, 1999 and 2001–2012.

Fig. 3 (a) Accumulated number of anglers, (b) proportion (%) of number of anglers in a fishing boat, (c) mean fishing experience of anglers, (d) mean fishing duration, (e) mean number of fishing rod per angler and (f) number of hooks per fishing rod used by anglers of sockeye salmon in Lake Toya, Japan during 1998, 1999 and 2001–2012.

Fig. 4 Mean (full line) standardized CPUE trend of sockeye salmon from recreational angling in Lake Toya, Japan during 1998, 1999 and 2001–2012. The two dotted lines denote lower and upper units of mean standardized CPUE.

Fig. 5 Plots of residuals against predicted values (left) and normal quantile–quantile (right) from the negative binomial generalized linear model (Negative–binomial GLM) fitted to recreational angling of sockeye salmon in Lake Toya during 1998, 1999 and 2001–2012.

Table 1. Correlation coefficients between continuous variables fitted to the model from angling of sockeye salmon in Lake Toya, Japan during 1998, 1999 and 2001–2012.

	Age	Experience	Duration	Angler	Rod	Hook
Age	1					
Experience	0.2	1				
Duration	0.1	–0.1***	1			
Angler	–	–0.1***	–	1		
Rod	–	–	–	–0.4***	1	
Hook	0.1***	–0.3***	–	–	0.3***	1

***: P<0.001 **: P<0.01 –: No correlation

Table 2. Information on three generalized linear models (GLMs) with different error distributions used to select an optimum model for standardizing catch and effort data from recreational angling of sockeye salmon in Lake Toya, Japan during 1998, 1999 and 2001–2012.

Model	Distribution	Link function	Response variable	Dispersion
Model 1	Gaussian	Log	CPUE	0.09
Model 2	Poisson	Log	Catch	4.89
Model 3	Binomial	Log	Catch	1.16

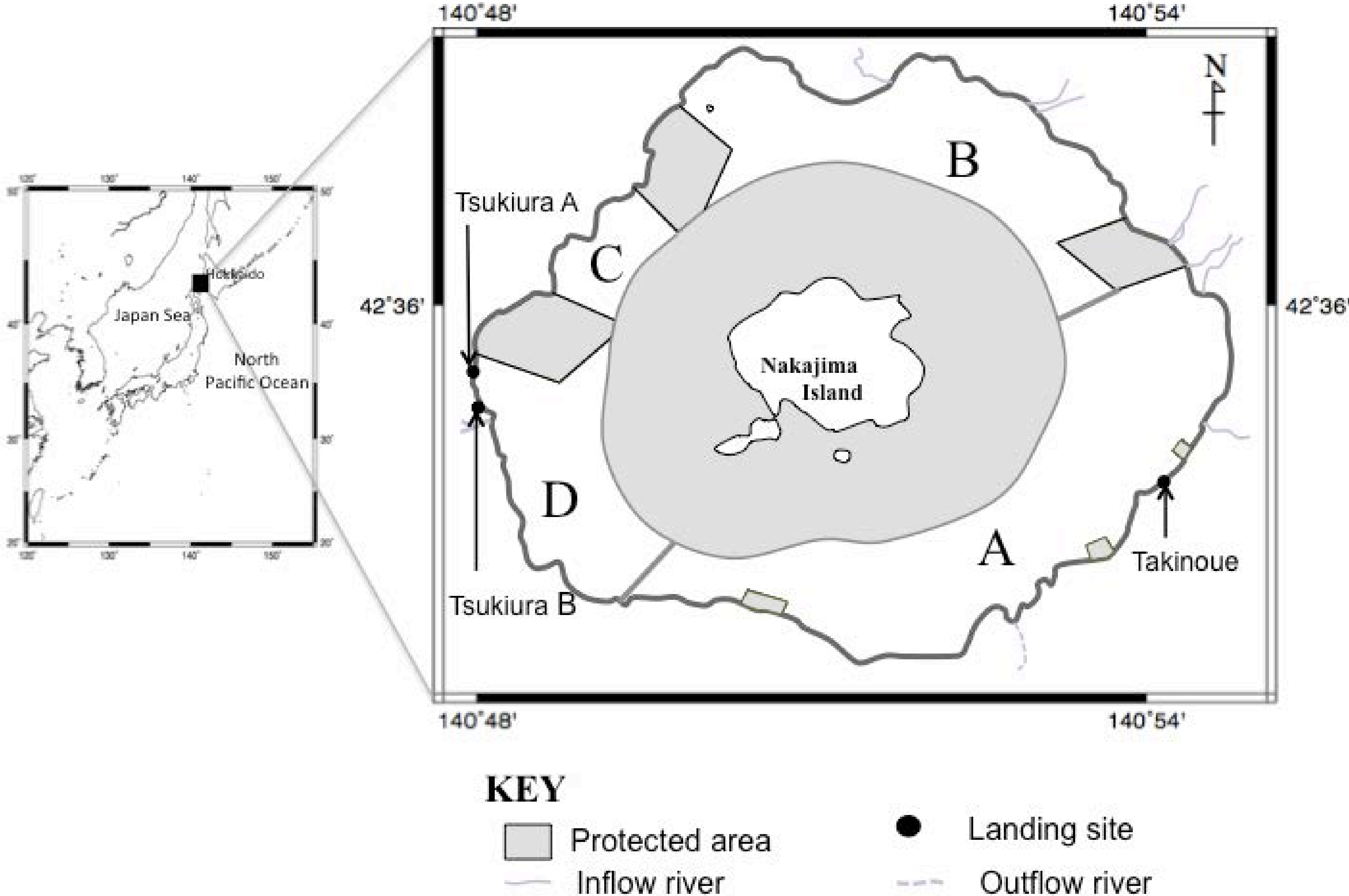
Table 3. Analysis of deviance for the negative binomial generalized linear model fitted to the recreational angling data of sockeye salmon in Lake Toya, Japan during 1998, 1999 and 2001–2012.

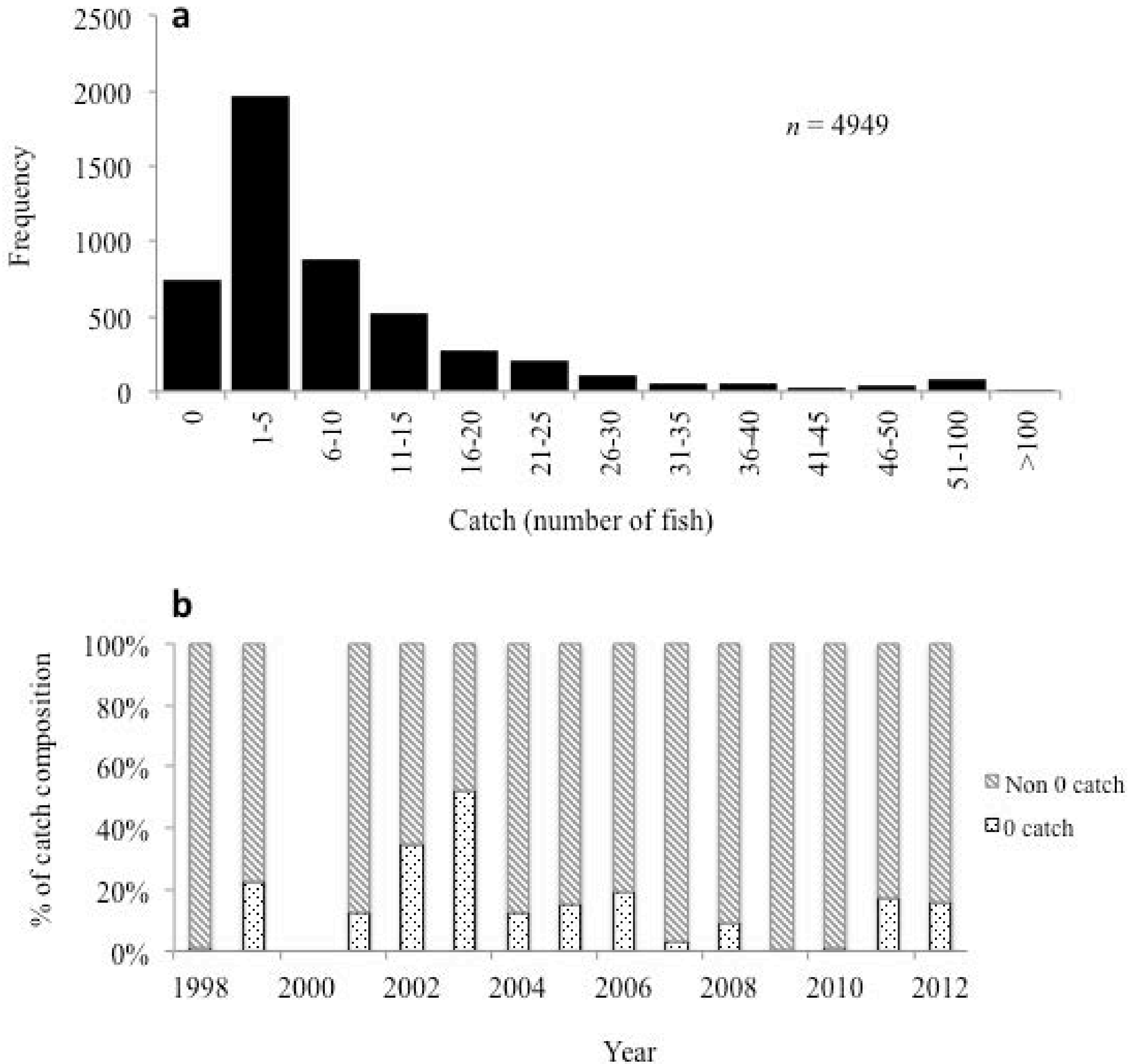
			Residual		
	DF	Deviance	DF	Deviance	*P*-value
Null hypothesis			4949	10491.8	
Year	13	3552.3	4936	6939.5	<0.001***
Week	3	340.6	4933	6598.9	<0.001***
Area	3	69.6	4929	6529.3	<0.001***
Age	1	69.0	4928	6460.3	<0.001***
Experience	1	3.4	4927	6456.9	0.06
Duration	1	308.3	4926	6148.6	<0.001***
Rod	1	49.4	4925	6099.2	<0.001***
Year * Week	39	439.6	4886	5659.6	<0.001***

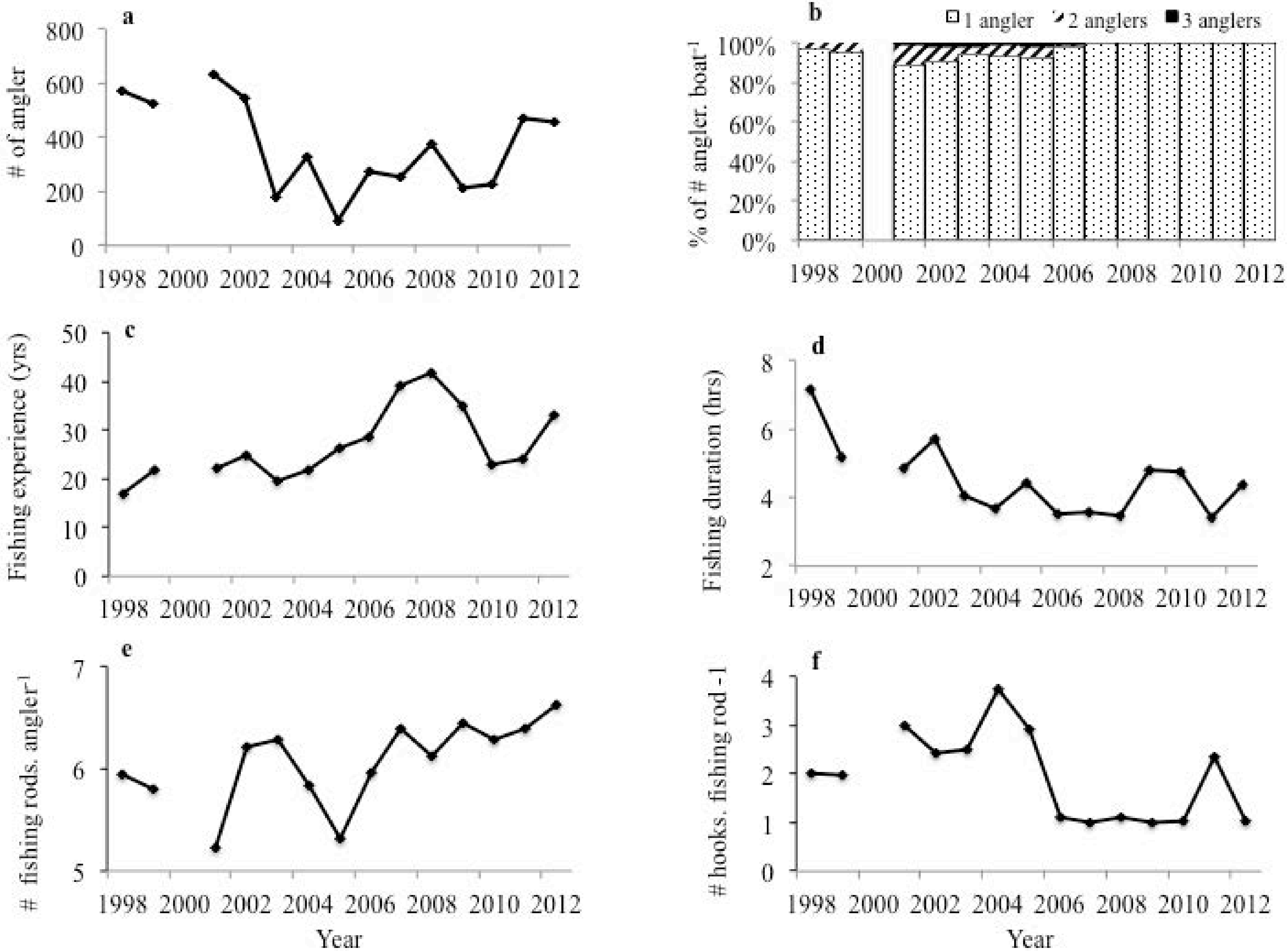
Table 4. Specific parameters (coefficients) from the best model used to standardize catch and effort data of sockeye salmon from recreational angling in Lake Toya, Japan during 1998, 1999 and 2001–2012

Level	Estimate	SE	*P*-value	Level	Estimate	SE	*P*-value
Intercept	2.678	0.145	<0.001***	2008*Week 2	0.139	0.163	0.394
1999	–1.378	0.085	<0.001***	2009*Week 2	0.027	0.188	0.885
2001	–0.827	0.075	<0.001***	2010*Week 2	–0.220	0.184	0.231
2002	–2.461	0.099	<0.001***	2011*Week 2	–0.059	0.148	0.687
2003	–2.246	0.132	<0.001***	2012*Week 2	–0.659	0.156	<0.001***
2004	–0.863	0.099	<0.001***	1999*Week 3	–0.195	0.172	0.258
2005	–0.931	0.127	<0.001***	2001*Week 3	–0.324	0.162	0.046*
2006	–2.133	0.113	<0.001***	2002*Week 3	0.947	0.181	<0.001***
2007	0.065	0.109	0.554	2003*Week 3	–0.739	0.430	0.086
2008	–1.438	0.107	<0.001***	2004*Week 3	1.040	0.199	<0.001***
2009	0.482	0.117	<0.001***	2005*Week 3	–0.290	0.372	0.435
2010	–0.622	0.135	<0.001***	2006*Week 3	1.823	0.195	<0.001***
2011	–0.085	0.093	0.361	2007*Week 3	–0.420	0.201	0.037*
2012	–0.763	0.093	<0.001***	2008*Week 3	0.544	0.171	0.001**
Week 2	–0.220	0.097	0.023*	2009*Week 3	0.223	0.187	0.235
Week 3	–0.680	0.104	<0.001***	2010*Week 3	0.033	0.196	0.866
Week 4	–0.877	0.095	<0.001***	2011*Week 3	0.180	0.151	0.234
Area B	–0.347	0.134	0.078	2012*Week 3	–0.761	0.176	<0.001***
Area C	0.132	0.062	0.044	1999*Week 4	–0.063	0.173	0.715
Area D	0.305	0.067	0.793	2001*Week 4	–0.517	0.208	0.013*
Age	–0.011	0.002	0.188	2002*Week 4	1.146	0.153	<0.001***
Experience	–0.009	0.002	<0.001***	2003*Week 4	–1.106	0.570	0.052
Duration	0.073	0.005	0.079	2004*Week 4	1.186	0.158	<0.001***
Rod	0.088	0.011	<0.001***	2005*Week 4	–0.121	0.448	0.786
1999*Week 2	–0.714	0.155	<0.001***	2006*Week 4	1.157	0.189	<0.001***
2001*Week 2	–0.243	0.176	0.168	2007*Week 4	–0.282	0.175	0.107
2002*Week 2	0.061	0.171	0.720	2008*Week 4	0.531	0.171	0.002**
2003*Week 2	–0.519	0.235	0.027*	2009*Week 4	0.207	0.178	0.244
2004*Week 2	0.633	0.171	<0.001***	2010*Week 4	0.199	0.180	0.268
2005*Week 2	–0.639	0.451	0.157	2011*Week 4	0.257	0.142	0.070
2006*Week 2	1.109	0.199	<0.001***	2012*Week 4	–0.465	0.149	0.002
2007*Week 2	–0.234	0.170	0.169				

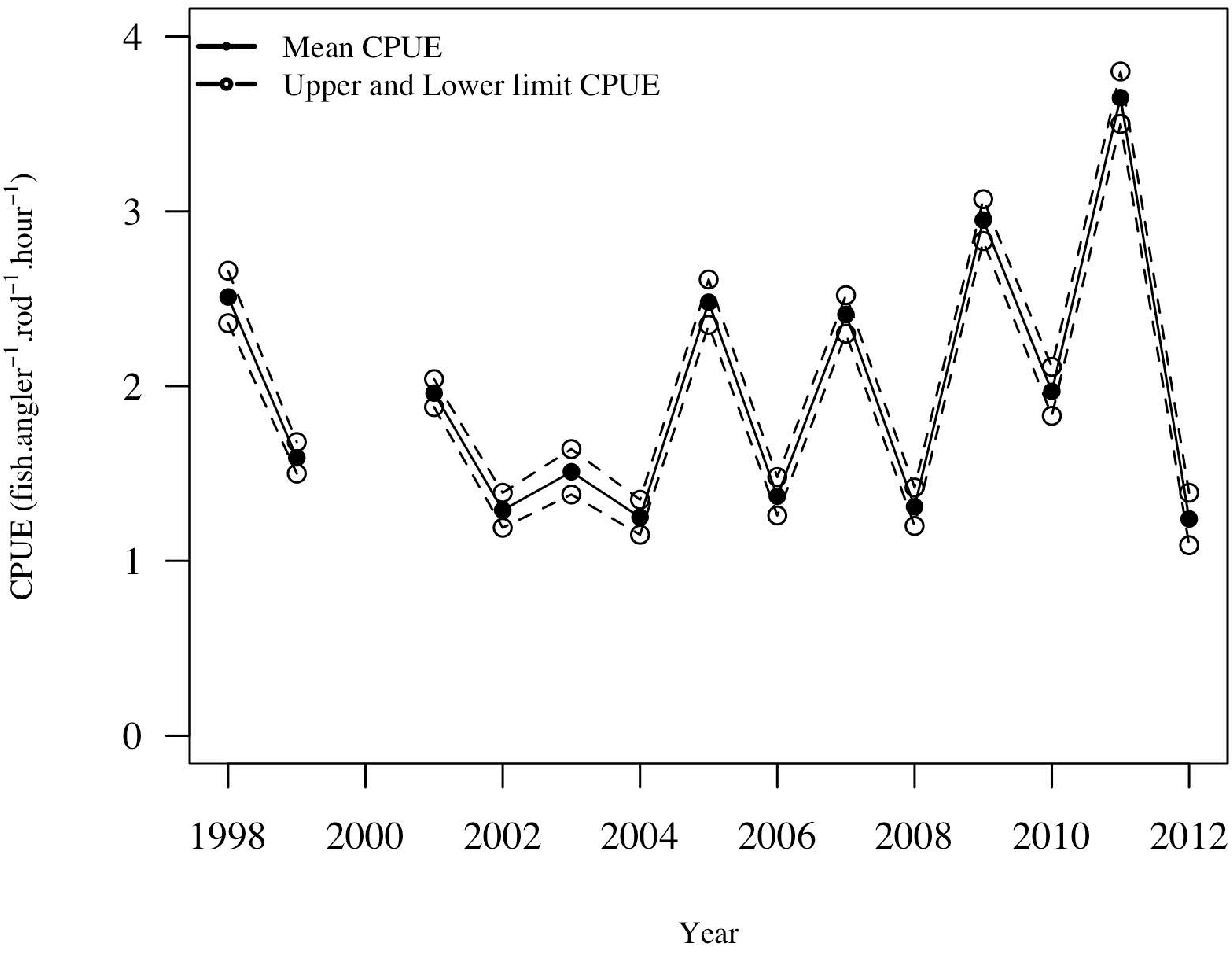
*** $P<0.001$ ** $P<0.01$ * $P<0.05$


140°48'
140°54'
42°36'
42°36'
140°48'
140°54'
N
B
C
A
D
Tsukiura A
Tsukiura B
Takinoue
Nakajima
Island
Japan Sea
North
Pacific Ocean
KEY
Protected area
Landing site
Inflow river
Outflow river

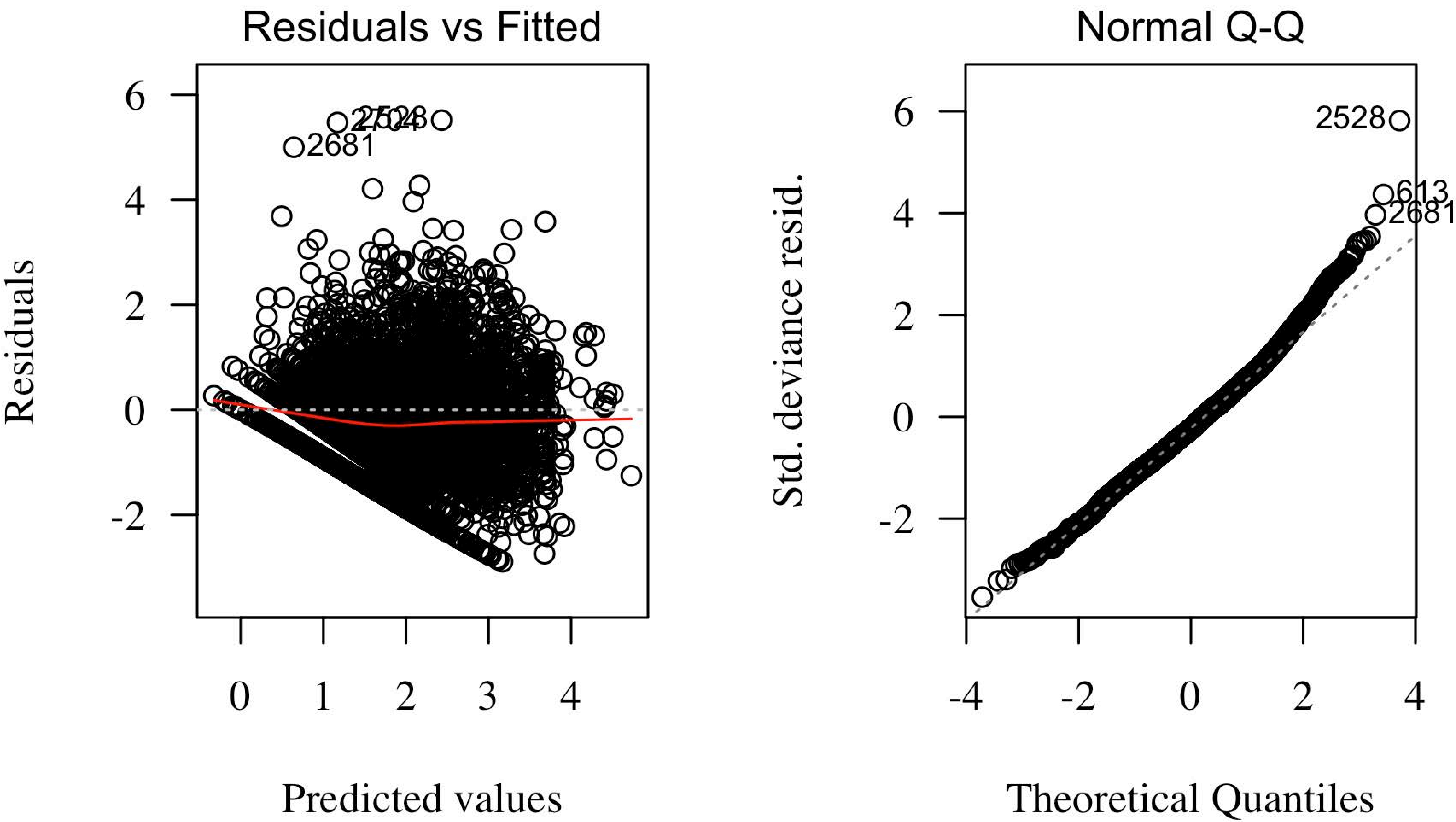

a
2500
2000
1500
1000
500
0
Frequency
n = 4949
0
1-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-100
>100
Catch (number of fish)
b
100%
80%
60%
40%
20%
0%
% of catch composition
Non 0 catch
0 catch
1998
2000
2002
2004
2006
2008
2010
2012
Year



a
# of angler
b
1 angler
2 anglers
3 anglers
% of # angler. boat-1
c
Fishing experience (yrs)
d
Fishing duration (hrs)
e
fishing rods. angler-1
f
hooks. fishing rod -1
Year
Year



Mean CPUE
Upper and Lower limit CPUE
CPUE (fish.angler^{-1}.rod^{-1}.hour^{-1})
0
1
2
3
4
1998
2000
2002
2004
2006
2008
2010
2012
Year


Residuals vs Fitted
Residuals
Predicted values
2681
6
4
2
0
-2
0
1
2
3
4
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
2528
613
2681
6
4
2
0
-2
-4
-2
0
2
4