Accounting for spatial, temporal and operational effects in the Catch Per Unit Effort standardization of Skipjack tuna in tuna drift gillnet fishery in Sri Lanka

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Abstract

Large meshed drift gillnets are widely used in the tuna fishery in Sri Lanka and the key target species for this gear is Skipjack tuna. The fishery conducted by this gear is characterized by the inboard engine fishing vessels, relatively longer fishing trips, use of supplementary fishing gear with gillnets, and harbour-based landings of multispecies catches. The present study was undertaken to standardize the catch per unit effort (CPUE) of skipjack tuna in the tuna drift gillnet fishery in Sri Lanka. Ten years of port sampling data (2013- 2022) were used for the CPUE standardization. A delta-lognormal model comprising a Gaussian-based Generalized Linear Model (GLM) for positive catch rates and a Bernoulli-based GLM for binary data of skipjack tuna was used for the CPUE standardization. The explanatory variables considered for the study include year, month, vessel category, gear used, number of net panels used, trip duration, gear setting time, and fishing area. All variables except the "fishing area" in Gaussian-based GLM were significant at 0.01 level. The abundance index of skipjack tuna is largely influenced by the "vessel category", "gear" and "year" variability. A remarkable variation in the annual abundance index was observed during the studied period. A similar standardized CPUE series obtained for an extended period could perhaps be beneficial in the future when stock assessments of skipjack tuna in the Indian Ocean are conducted.

Key words: Sri Lanka, Indian Ocean, tuna drift gillnet fishery, skipjack tuna, CPUE standardization

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Introduction

The tuna fishery in Sri Lanka is conducted by multiday and single-day fishing crafts in both the high seas and the Sri Lankan Exclusive Economic Zone (EEZ) targeting tuna and tuna-like species. Whereas multiday fishing crafts which are semi-industrial mainly engage in the tuna fishery, some artisanal single-day fishing crafts which are operated seasonally in the coastal waters also catch tuna and tuna-like species. About 4800 multiday fishing crafts registered under the Department of Fisheries and Aquatic Resources (DFAR) in Sri Lanka operate targeting tuna and tuna-like fish. The multiday fishing fleet has grown from about 1,300 vessels in 2005 to over 4,800 in 2019 (MoF, 2021). The landings have only grown from 66 710 t to 172 910 t during the same period. The key species in tuna fishery in Sri Lanka is Skipjack tuna and the relative contribution of this species in the present tuna catch is over 40%. Skipjack tuna is mostly harvested by large meshed drift gillnets.

The aim of the present work is to standardize the Catch Per Unit Effort (CPUE) of Skipjack tuna in the tuna drift gillnet fishery of Sri Lanka with respect to spatial, temporal, and fishing operation-related parameters that may influence to change in CPUE.

Materials and methods

Port sampling

The port sampling data in the tuna fishery of Sri Lanka was used for this study. Accordingly, port sampling data collected by the NARA enumerators based on fishery harborus from 2013 – 2022 (ten years of data) were made use of to carry out the CPUE standardization of skipjack tuna. When sampling a fishing boat, enumerators record relevant information about the fishing operation such as departure date, arrival date, number of fishing days, vessel category, used gear type, gear-specific information (e.g., number of net panels used in the gillnet fishery), fishing area, trip duration and gear setting time. Also, the landed catch by species is recorded. The data are stored in the new PELAGOS database introduced in 2013 for handling port sampling data.

Data extraction

Port sampling data pertaining to gillnet fishing operations conducted during 2013 – 2022 by inboard engine fishing crafts was extracted from the PELAGOS database. Skipjack tuna is normally the main catch in the tuna gillnet fishery. Since gillnets sometimes had been operated with another gear, such gear combinations were also taken into account for CPUE standardization. Other gears operated in the tuna drift gillnet fishery include handline, longline, ring net and troll line.

Data preparation for CPUE standardization

The CPUE data were prepared in the form of Skipjack tuna catch in kilograms per boat per fishing day and this was used as the response variable for CPUE standardization. In the process of estimating the CPUE in this form, it was difficult to estimate the CPUE for certain boats since missing values were found in the parameter of "fishing days" in approximately 8% of the total records. In such instances, the average value for fishing days calculated from the remaining data records was used in order to estimate the CPUE.

The categorical predictor variable considered in the data set are year (10 levels: 2013, 2014, … 2022), month (12 levels: January -1. February – 2, … December – 12), season (4 levels: 1: January to March; 2: April to June, 3; July to September; 4: October to December), vessel category (5 levels: IDAY, IMUL01, IMUL02, IMUL03, IMUL04), gear type (5 levels: GN; GL, GH, GR, GT), trip duration in days (TD) (4 levels: 1:1 to 15; 2: 16 to 30; 3: 31 to 45; 4: 46 to 60), number of net panels used (NP) (4 levels:1: 1 to 30; 2:31 to 60; 3:61 to 90; 4:90+), fishing zone (4 levels: EEZ, SIO, ARS, BOB), and gear setting time (3 levels: day, night, both day and night). Additional details about vessel categories, gear types, and fishing zones with relevant abbreviations used are provided in Table 1.

Table 1. Information relevant to vessel categories, gear types, and fishing zones in tuna drift gillnet fishery in Sri Lanka

Abbreviation	Description
Vessel categories	
IDAY	8.8 - 9.8 mm (28' - 34') displacement hull. FRP or wooden. Inboard engine (single) - 40 HP No ice box or insulated fish hold, no gear hauler, or acoustic equipment but, may have GPS Single day boats - assumed to be fishing in COASTAL WATERS
IMUL01	8.8 - 9.8 m (28' - 34') displacement hull. FRP wooden. Inboard engine (single) - 40 HP Insulated fish hold - no gear hauler, may have GPS/sounder/fish finder Multi-day boats-assumed to be fishing in OFFSHORE/ DEEP SEA WATERS
IMUL02	9.8 - 12.2 m (34' - 40') displacement hull. FRP wooden. Inboard engine (single) - 60 HP - Insulated fish hold and may have gear hauler/GPS/sounder/fish finder Multi-day boats-assumed to be fishing in OFFSHORE/ DEEP SEA WATERS
IMUL03	12.2 - 15.2 (40' - 50') displacement hull. FRP or wooden Inboard engine (single) - 60 + HP Insulated fish hold and may have freezer facilities. Gear hauler/GPS/sounder/fish finder Multi-day boats-assumed to be fishing in OFFSHORE/ DEEP SEA WATERS
IMUL04	15.2 - 18.3 m displacement hull. FRP
Gear types	
GN	Gillnet alone
GL	Gillnet operated with longline
GH	Gillnet operated with hand line
GR	Gillnet operated with ring net
GT	Gillnet operated with troll line
Fishing zones	
EEZ	Exclusive Economic Zone in Sri Lanka

SIO	Southern Indian Ocean
ARS	Arabian Sea
BOB	Bay of Bengal

Fitting Generalized Linear Models (GLMs) for CPUE standardization

CPUE data of skipjack tuna consist of many zero values. Therefore, the delta-lognormal approach was used for CPUE standardization (Stefánsson, 1996). This method is a modification of the delta-distribution approach, which fits into the GLM framework: parameters were estimated by the maximum likelihood method. Accordingly, two GLMs were fitted: to model the positive catch rates, a lognormal model was built, and to model the zero and non-zero catch rates (0/1 binary data in the response variable), a binomial model was built. The predictor variables used in the two models are year, month, vessel category, gear type, trip duration, number of net panels used, and gear setting time.

The fitted values of the overall model were obtained from the two sub-models. Furthermore, year effects and other main effects were derived from these models. All the statistical analyses were carried out using R software version 4.1.3 (R Development Core Team, 2022).

Results

Data visualization

The frequency distribution of skipjack tuna CPUE was skewed, having a large number of zero values. Therefore, the histogram was presented on a logarithmic scale by adding a small constant (0.001) to CPUE and positive CPUE in the logarithmic scale as well (Fig. 1).

The Log (CPUE>0) fluctuates over the years but, seasonal fluctuations are considerably low in the log scale (Fig. 2). When considering the monthly fluctuations, a considerable fluctuation can be observed. Therefore, “month” was considered as an explanatory variable in the GLM modeling. Accordingly, the highest and lowest mean catch rates were reported in September and November respectively. Moreover, catch rates apparently depend on other variables as well. Very few observations were made regarding the “IMUL04” vessel type. This is because these boats are operated occasionally in tuna drift gillnet fishery.

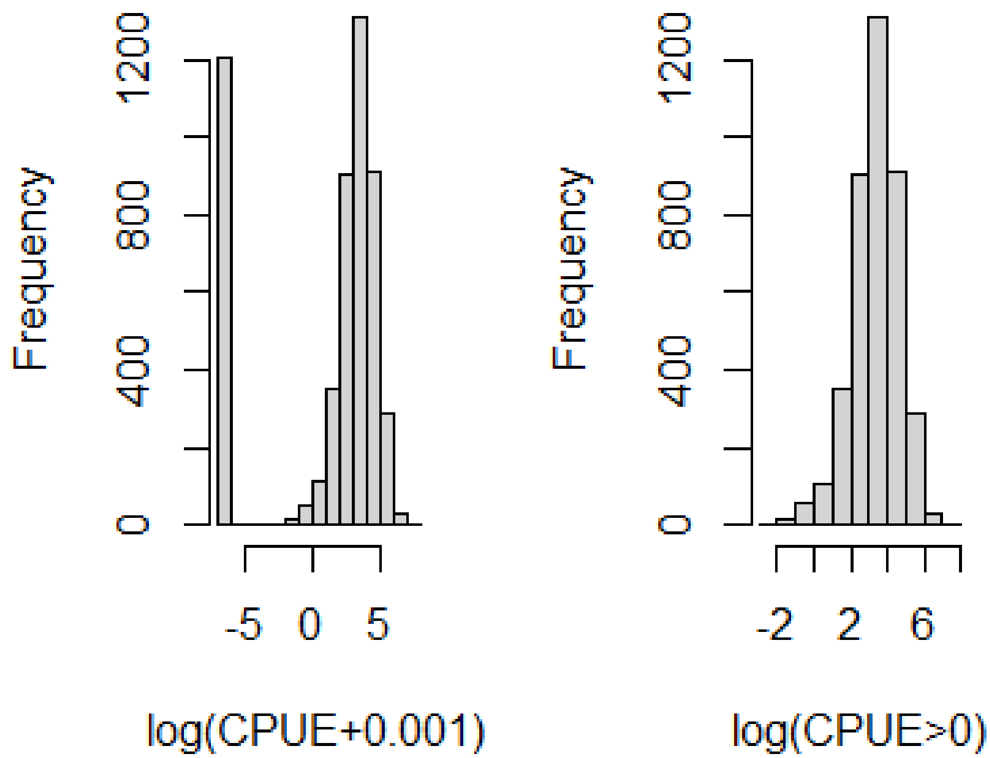
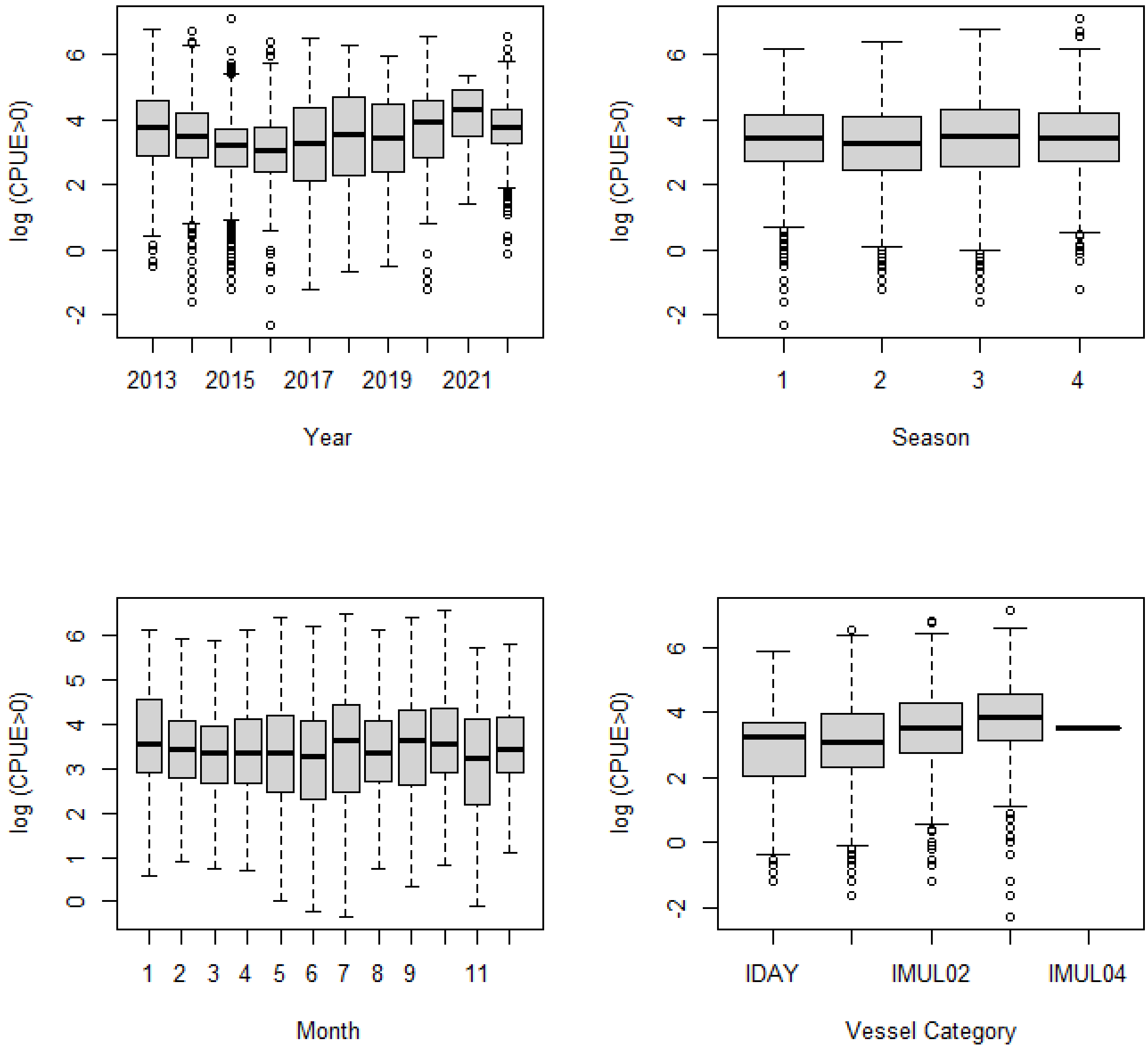


Fig.1. Data summaries of skipjack tuna CPUE in terms of catch in kg per boat per fishing day in the tuna drift gillnet fishery in Sri Lanka, 2013- 2022: (a) histogram of log-transformed slightly shifted CPUE, log (CPUE+ .001) and (b) histogram of log-transformed positive CPUE, log (CPUE>0)


log (CPUE>0)
-2 0 2 4 6
2013 2015 2017 2019 2021
Year
log (CPUE>0)
-2 0 2 4 6
1 2 3 4
Season
log (CPUE>0)
0 1 2 3 4 5 6
1 2 3 4 5 6 7 8 9 11
Month
log (CPUE>0)
-2 0 2 4 6
IDAY IMUL02 IMUL04
Vessel Category

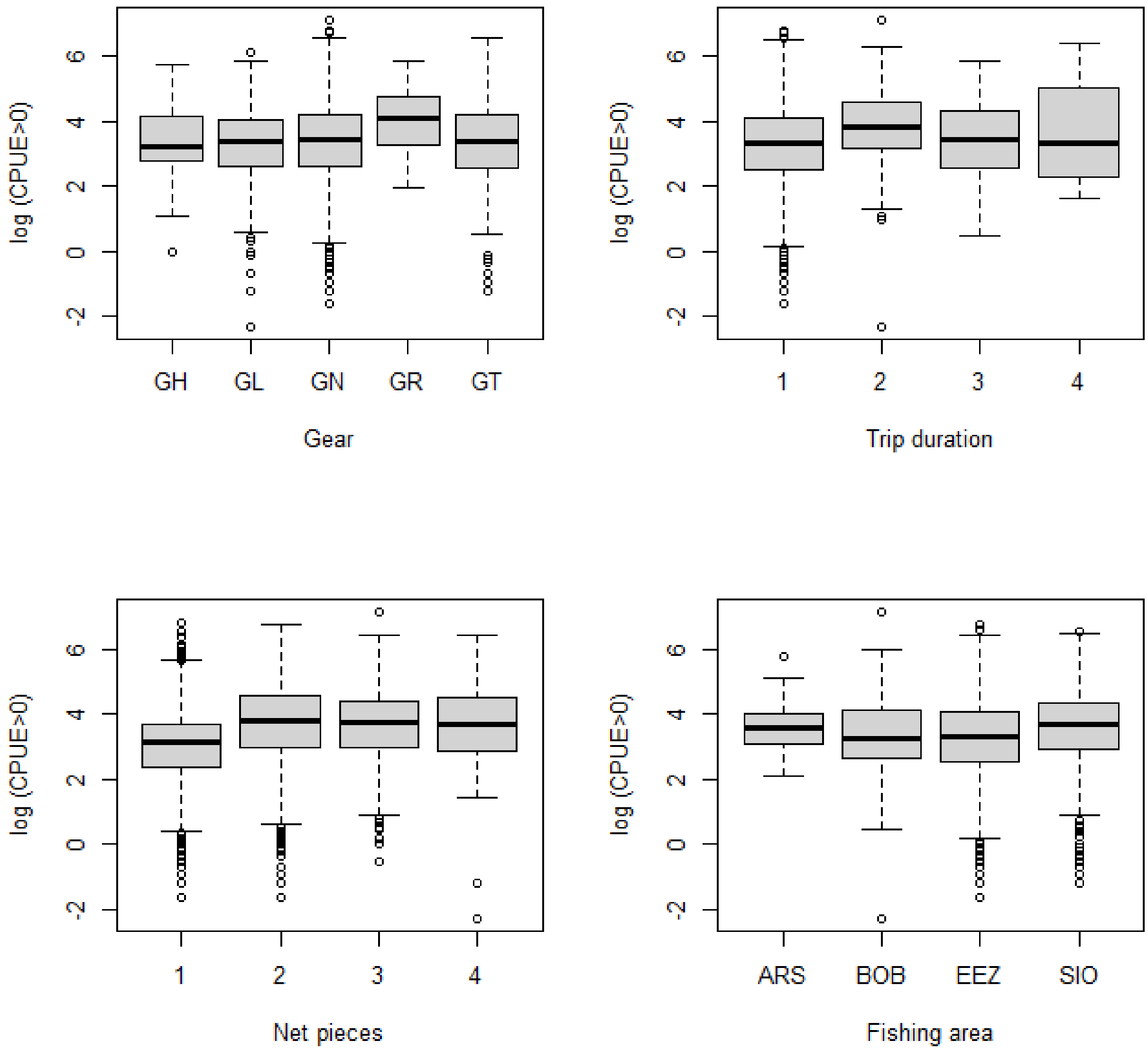


Fig 2. Box plot of non-zero CPUE of skipjack tuna in the tuna drift gillnet fishery, Sri Lanka in log scale with respect to parameters (a) year (2013, 2014, …, 2022), (b) season (1: January – March; 2: April -June, 3; July – September; 4: October - December), (c) month ((January -1. February – 2, … December – 12), (d) vessel category (IDAY, IMUL01, IMUL02, IMUL03, IMUL04), (e) gear type (GN; GL, GH, GR, GT), (f) trip duration (TD) (1:1 - 15; 2: 16 - 30; 3: 31 - 45; 4: 46 - 60), (g) number of net panels used (NP) (1: 1 -30; 2:31-60; 3:61-90; 4:90+), fishing area (EEZ, SIO, ARS, BOB), and (h) gear setting time (day, night, both day and night)

Positive catch rates of skipjack tuna

The analysis of deviance for the Gaussian-based GLM model fitted to skipjack tuna positive catch rates shows that all factors except the "fishing area" considered in the model are significant ($p < 0.01$) (Table 2). The total deviance of the model is mostly explained by "number of net panels", "vessel category" and "year" respectively.

Table 2. Analysis of deviance table for the Gaussian-based GLM fitted to skipjack tuna positive catch rates in the tuna drift gillnet fishery in Sri Lanka: 2013 – 2022 (Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1)

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL			3255	17738902		
Year	9	433185	3246	17305717	10.0250	2.491e-15 ***
Month	11	247085	3235	17058632	4.6785	3.921e-07 ***
VC	4	481849	3231	16576783	25.0902	< 2.2e-16 ***
Gear	4	176043	3227	16400740	9.1667	2.315e-07 ***
TD	3	56204	3224	16344536	3.9021	0.008536 **
NP	3	732130	3221	15612406	50.8302	< 2.2e-16 ***
FA	3	30385	3218	15582021	2.1096	0.096889
GST	2	142227	3216	15439794	14.8117	3.952e-07 ***

VC – vessel category, TD -trip duration, NP- number of net panels used, FA – fishing area, GST- gear setting time

The relative indices of skipjack tuna in the gillnet fishery estimated using Bernoulli-based and Gaussian-based GLM models were evidence for the annual fluctuations of the CPUE (Fig. 3).

0/1 binary data of CPUE

The analysis of deviance for the Bernoulli-based GLM model fitted to binary data of skipjack tuna shows that all factors considered in the model are significant (p < 0.001) (Table 3). The total deviance of the model is mostly explained by “Vessel category”, “Gear” and “Year” respectively.

Table 3. Analysis of deviance table for the Bernoulli-based GLM fitted to skipjack tuna binary catch rates in the tuna drift gillnet fishery in Sri Lanka: 2013 – 2022 (Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			4248	4620.5	
Year	9	135.011	4239	4485.4	< 2.2e-16 ***
Month	11	54.223	4228	4431.2	1.075e-07 ***
VC	4	307.825	4224	4123.4	< 2.2e-16 ***
Gear	4	165.358	4220	3958.0	< 2.2e-16 ***
TD	3	27.923	4217	3930.1	3.769e-06 ***
NP	3	48.994	4214	3881.1	1.308e-10 ***
FA	3	33.729	4211	3847.4	2.260e-07 ***
GST	2	19.640	4209	3827.8	5.434e-05 ***

VC – vessel category, TD -trip duration, NP- number of net panels used, FA – fishing area, GST- gear setting time

Standardized CPUE indices

The relative indices of skipjack tuna in the tuna drift gillnet fishery estimated using Bernoulli-based and Gaussian-based GLM models were evidence for the annual fluctuations of the CPUE (Fig. 3).

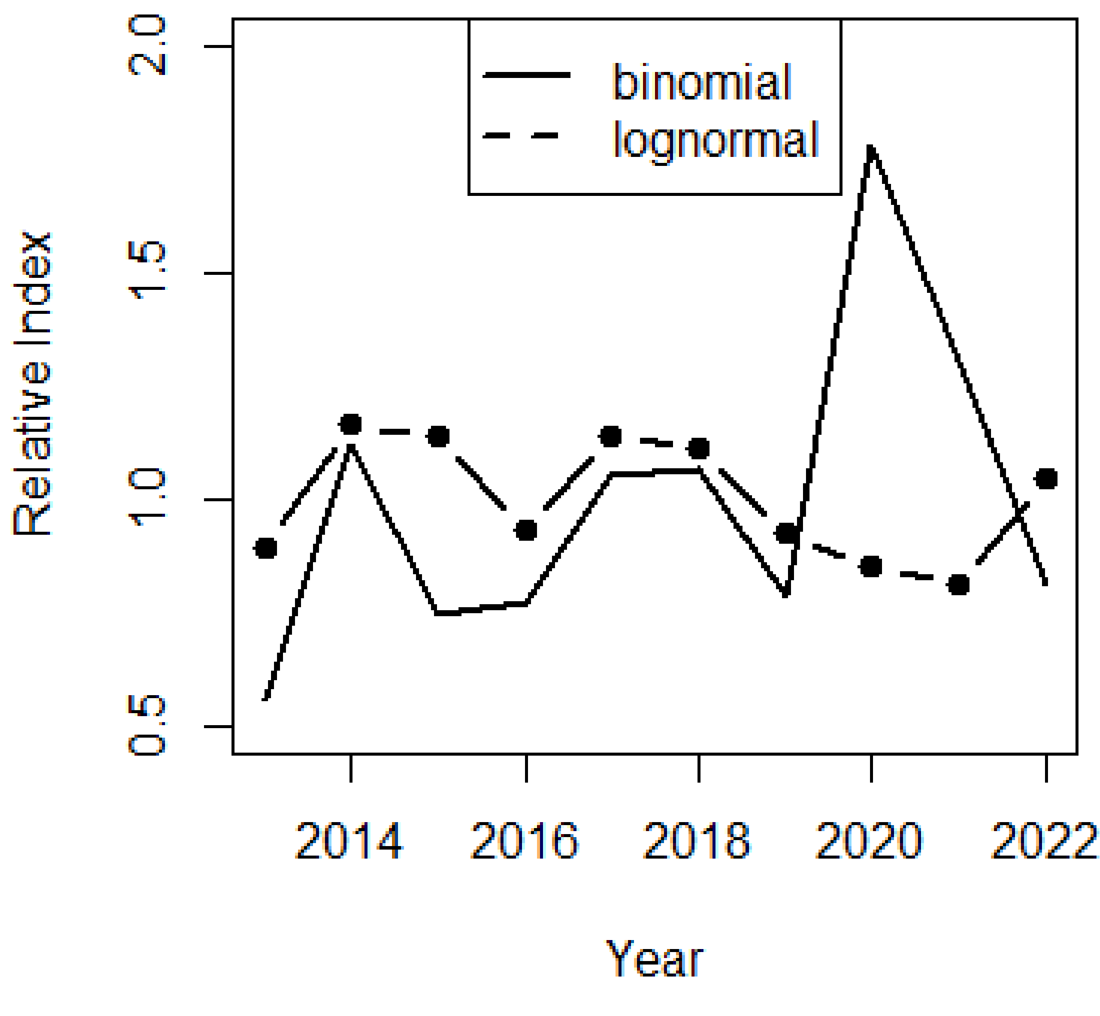


Fig. 3. Standardized relative indices of skipjack tuna in the tuna drift gillnet fishery, Sri Lanka using Bernoulli-based and Gaussian-based GLM models

The standardized CPUE indices were obtained using the results of Bernoulli-based and Gaussian-based GLM models. The lowest standardized CPUE indices were reported at the start of the time series in 2013 (Fig. 4). The highest value for standardized CPUE was reported in 2020.

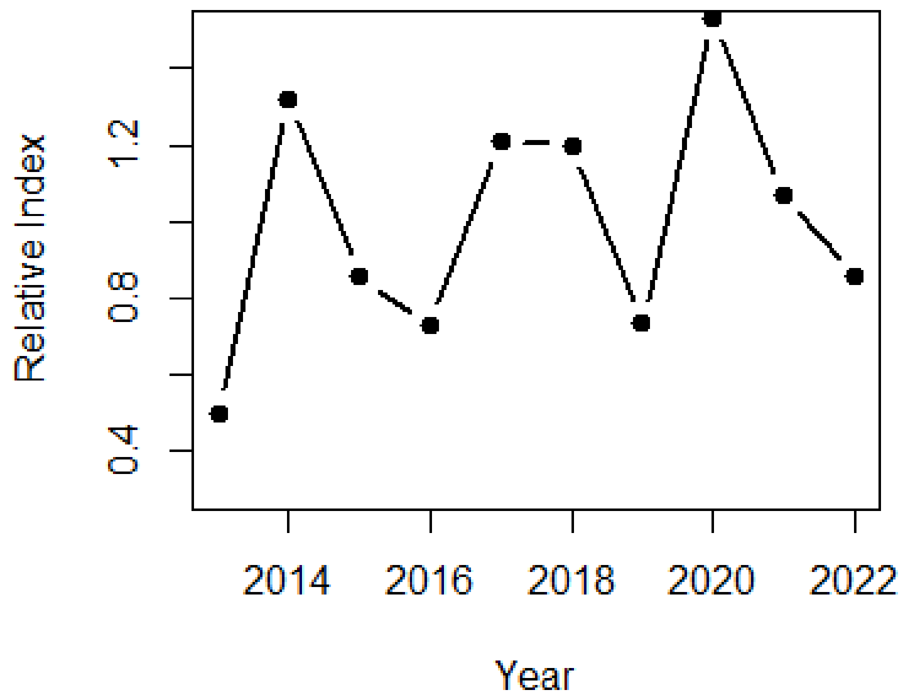


Fig 4. Standardized catch per unit effort (CPUE) indices of skipjack tuna in the tuna drift gillnet fishery, Sri Lanka using the delta-lognormal method. Values were scaled by dividing their means.

Discussion

The standardized CPUE indices constructed for skipjack tuna in Maldives pole and line fishery are currently used for assessing the stock status of skipjack tuna in the Indian Ocean. Such abundance indices for skipjack tuna have been constructed so far only for a few other fisheries in the Indian Ocean (Soto et al., 2013; Katara et al., 2017; Novianto et al., 2019).

CPUE standardization of skipjack tuna in the tuna drift gillnet fishery in Sri Lanka was conducted with the aim of constructing a new standardized CPUE series for skipjack tuna in the Indian Ocean. Such a standardized CPUE series obtained for an extended period could perhaps be beneficial when future stock assessments of skipjack tuna in the Indian Ocean are conducted. Since Sri Lanka's multiday fishing crafts are operated in a wider geographical area in the Indian Ocean covering Sri Lanka EEZ, the Bay of Bengal area, the Southern Indian Ocean, and the Arabian Sea, abundance indices derived from landing data of this tuna fishery might give a reasonable representation of the abundance of skipjack tuna in the Indian Ocean.

Though eight predictor variables pertaining to the spatial, temporal, and fishing operation effects were considered for the CPUE standardization, the abundance index of skipjack tuna is largely influenced by the "vessel category", "gear" and "year" variability. The misreporting or underreporting of spatial data relevant to fishing areas is likely the probable reason for the least recognition of that variable in CPUE standardization.

Conclusions

Since catch rates of skipjack tuna in the tuna drift gillnet fishery in Sri Lanka comprise many zero values, applying of delta-lognormal approach for catch per unit effort standardization is appropriate. All explanatory variables used in GLM models except "fishing area" in the Gaussian-based GLM model were statistically significant but, explained deviances by them were relatively low. The abundance index of skipjack tuna is largely influenced by the "vessel category", "gear" and "year" variability. However, spatial data considered in the study do not significantly contribute to CPUE standardization. The annual abundance index of skipjack tuna varies largely throughout the studied period.

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