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BLUE MARLIN (*MAKAIRA NIGRICANS*) STANDARDIZED INDICES OF ABUNDANCE FROM THE U.S. PELAGIC LONGLINE AND RECREATIONAL TOURNAMENT FISHERIES

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SUMMARY

Indices of relative abundance for blue marlin in the Atlantic Ocean are presented for two U.S. fisheries, the pelagic longline bycatch fishery and the recreational billfish tournament fishery. The longline index is based on scientific observer reported catch and effort for individual longline sets; the tournament index is based on records of catch and effort aggregated by tournament. Model selection was performed on a set of defined models representing alternative hypotheses of covariate effects on catchability. The null model, CPUE~Year+Area+Quarter, was compared first with Year+Habitat and Year+Sea_Temperature models to determine primary factors for inclusion. A repeated measures model was also tested for tournaments. The final longline index included year, area, quarter, habitat, hook type, hooks/float, and day/night effects. The final tournament index included year, area, quarter, with a random tournament effect. The precise location of fishing sets for longlines resulted in more accurate habitat assignment compared to tournaments, where only the fishing port was known. The random effect model for individual tournaments likely captured much of the variation that might be attributed to differences in habitat or other covariates.

RÉSUMÉ

Des indices de l'abondance relative du makaire bleu dans l'Atlantique sont présentés pour deux pêcheries américaines, à savoir la pêcherie palangrière pélagique de prises accessoires et la pêcherie de tournois récréatifs d'istiophoridés. L'indice palangrier se fonde sur la prise et l'effort déclarés par les observateurs scientifiques pour chaque opération palangrière alors que l'indice des tournois est fondé sur les registres de la prise et de l'effort agrégés par tournoi. La sélection du modèle a été effectuée sur un jeu de modèles définis représentant des hypothèses alternatives des effets des covariables sur la capturabilité. Le modèle nul, CPUE ~ Année + Zone + Trimestre, a été comparé d'abord avec les modèles Année+ Habitat et Année+ Température_Mer pour déterminer les facteurs primaires d'inclusion. Un modèle de mesures répétées a également été testé pour les tournois. L'indice palangrier final comprenait l'année, la zone, le trimestre, l'habitat, le type d'hameçon, les hameçons/flotteurs et les effets jour/nuit. L'indice final du tournoi incluait l'année, la zone, le trimestre, avec un effet de tournoi aléatoire. L'emplacement précis des opérations de pêche des palangriers a permis d'attribuer des habitats plus précis par rapport aux tournois, où seul le port de pêche était connu. Le modèle à effets aléatoires pour les tournois individuels a probablement saisi une grande partie de la variation qui pourrait être attribuée aux différences d'habitat ou à d'autres covariables.

RESUMEN

Se presentan los índices de abundancia relativa para la aguja azul del Atlántico para dos pesquerías estadounidenses, la pesquería de captura fortuita de palangre pelágico y la pesquería de torneos recreativos de istiofóridos. El índice del palangre se basa en la captura y esfuerzo comunicados por los observadores científicos para cada lance individual de palangre y el índice de torneos se basa en los registros de captura y esfuerzo agregados por torneo. La selección del modelo se llevó a cabo entre un conjunto de modelos definidos que representan hipótesis alternativas de efectos covariables sobre la capturabilidad. El modelo nulo, CPUE~Año+Área+Trimestre, fue comparado en primer lugar con los modelos Año+Hábitat y Año+Temperatura del mar para determinar los principales factores para su inclusión. Se probó también un modelo de medidas repetidas para los torneos. El índice de palangre final

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incluía año, área, trimestre, hábitat, tipo de anzuelo, anzuelos/flotador y efectos día/noche. El índice del torneo final incluía año, área, trimestre y un efecto aleatorio de torneo. La localización precisa de los lances pesqueros del palangre dio como resultado una asignación de hábitat más precisa, donde solo se conocía el puerto de pesca. El modelo del efecto aleatorio para los torneos individuales probablemente capturó gran parte de la variación que podría atribuirse a diferencias en el hábitat o a otras covariables.

KEYWORDS

Blue marlin, catch/effort, longlining, recreational fisheries

1. Introduction

This paper presents two indices of relative abundance from U.S. fisheries for consideration in the stock assessment of Atlantic blue marlin. Catch rates from the United States pelagic longline (PLL) fleet and recreational billfish tournaments were standardized to generate abundance indices for the periods 1993 to 2016 (longlines) and 1974 to 2016 (tournaments). The U.S. PLL fleet operates across a wide area of the western North Atlantic Ocean, Gulf of Mexico and the Caribbean Sea, targeting swordfish (*Xiphias gladius*) and tunas primarily. Marlins are neither targeted nor landed by the fleet, but are still subject to incidental catch. Longline indices of relative abundance were prepared using catch and effort information collected through the U.S. Pelagic Observer Program (PLOP). The U.S. billfish tournament fishery is a recreational hook and line fishery. Tournament catch and effort data from tournaments along the Atlantic east coast (including the Bahamas), Gulf of Mexico, and Caribbean (U.S. Virgin Islands and Puerto Rico) have been collected by the program since 1972.

The analytical approaches to standardization were based on recent best practices and lessons learned from two large-scale CPUE modeling endeavors, the pelagic longline simulation modeling of Goodyear et al. (2018) and the joint CPC longline index workshops for bluefin tuna (SCRS-2016-188, SCRS-2017-035). Blue marlin habitat suitability (H50 predictions, see Goodyear et al. 2018) in relation to fishing location was modeled along with standard covariates (area, season, gear characteristics, species targeting etc.) to assess the influence of habitat on CPUE in comparison to time/area and other factors. The modeling was conducted as a set of sequential hypothesis tests to first evaluate habitat and sea surface temperature versus time-area standardizations typically conducted, and then to evaluate the gear configuration and targeting covariates (longline data). For recreational tournaments, the effect of treating individual tournaments as a random effect on catch rates was evaluated. The principle for this modeling approach is that the characteristics of individual tournaments (e.g., gear restrictions, prize categories, location, seasonality, and fishing methods) may be highly influential on observed catch rates, but the data do not provide sufficient information to model these covariates separately.

2. Materials and Methods

2.1 Pelagic longline observer program

Individual observers from the U.S. Pelagic Longline Observer Program are assigned to subsample approximately 8% of fishing trips for the U.S. PLL fleet, and record information on catch, fishing gear, environmental conditions, and vessel characteristics for each trip. The longline fishing grounds for the U.S. PLL fleet extend from the Grand Banks in the North Atlantic to latitudes of 5-10°S, off the South America coast, including the Caribbean Sea and the Gulf of Mexico. Ten geographical locations of PLL fishing were used for the analysis (**Figure 1**): the Caribbean (CAR), Gulf of Mexico (GOM), Florida East Coast (FEC), South Atlantic Bight (SAB), Mid-Atlantic Bight (MAB), New England Coastal (NEC), Sargasso Sea (SAR), North Central Atlantic (NCA), Tuna North (TUN; between 5°N and 13°N latitude) and Tuna South (TUS; between 0° and 5°N latitude). Calendar quarters were used to account for seasonal fishery distribution (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec). Other factors examined in the analyses of longline catch rates included: habitat, sea surface temperature, target species, number of hooks between floats, average hook depth, hook size, hook type, and day versus night.

The pelagic longline fishery has operated under several time-area restrictions since 2000 due to management regulations related to swordfish and other species (Federal Register 2000, **Figure 1**). These restrictions include: the Desoto Canyon closure in the Gulf of Mexico (effective in 2000), the Florida East Coast closure (effective in 2001), and the Grand Banks closure (closed from July 17th 2001 – January 9th 2002). Two time-area closures also occurred: the Charleston Bump off the North Carolina coast (closed from February 1st – April 30th starting in 2001), the Bluefin Tuna Protection Area off the New England Coast (closed from June 1st – June 30th starting in 1999). For the present study, any sets located in closed areas prior to or after the closure were removed from the data set. For time-area closures, we removed data for that area and during the closed months from all years.

2.2 Recreational Billfish Tournament Survey

Catch and effort records from recreational billfish tournaments have been collected since 1972 either by NMFS observers or through submission by tournament organizers. Present U.S. regulations require all recreational tournaments to register and provide catch and effort data to the NMFS. Fishing effort is estimated from the number of boats registered in the tournament times the fishing hours per day. Records also include total number of fish hooked, and their fate (i.e. lost, released, tagged and released, or boated) by species, and morphometric information (size and weight) for boated fish. There are about 200 active tournaments registered in the system. Only recreational tournaments that targeted marlin were used for this analysis. Marlin tournament fishing is typically conducted by trolling offshore using lures, dead natural bait, or dead bait/lure combinations as terminal gear. However, other tournaments occasionally catch marlin as a bycatch while targeting sailfish, tuna, swordfish, or other highly migratory species (e.g., wahoo, mackerel) using a variety of other fishing methods (i.e., live bait drift fishing, chunk fishing, night fishing, etc.). Thus, fishing techniques other than daytime trolling with lures or bait fished in offshore waters were judged inappropriate for this analysis, following the data treatment in previous analyses. In addition, some tournaments have offshore and inshore components and target both offshore and inshore species during their events. In these tournaments, pure marlin fishing effort cannot be separated from other types of fishing; therefore, these tournaments were also judged as inappropriate for this analysis.

For analytical purposes, tournaments were grouped into six geographical areas, a) Caribbean region (CAR) (Puerto Rico, US Virgin Islands), b) US Gulf of Mexico (GOM), c) Florida including the Keys, d) South Atlantic (SAT) (North Carolina, South Carolina, Georgia), e) Bahamas (BAH), f) mid-Atlantic region (Delaware, Maryland, and Virginia) and g) the North Atlantic region (NAT) (New England). Seasonal trends were considered in the standardization by including yearly quarter s (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec). Other factors examined in the analyses of catch rates included, habitat (H50), sea surface temperature, and a random tournament effect.

2.3 Standardization models

Index standardization was conducted with generalized linear models ran in program R using the glmmADMB library (R Core Team, 2015). The statistical properties of the data were examined to select between one- or two-stage GLMs. For the longline data, a one-stage GLM (negative binomial family, log link function, with a log(effort) offset) was determined appropriate based on the fit of the negative binomial distribution to the distribution of observed catches. For the recreational tournament data, a two-stage GLM (delta-gamma model with a binomial regression, logit link function, on the observed frequency of occurrence and gamma regression, log link function, on the positive catch rates) was used due to data overdispersion not likely to be captured in a one-stage model. For the two-stage model, the standardized annual abundance predictions combined the least square means of the GLM's for the frequency of marlin occurrence and the catch rates of those tournaments that were successful.

3. Results and Discussion

The final set of explanatory variables in the longline standardization (negative binomial GLM) model included: year, area, quarter, habitat, hook type, hooks per float (a proxy for fishing depth), and day/night. The final set of explanatory variables for the recreational tournament standardization included: year, area, quarter, and tournament effect (random effect) for both the frequency of occurrence and positive catch rate models. **Tables 1 and 2** show the change in information criteria associated with factor inclusion used in model selection of longline and tournaments, respectively. **Tables 3 and 4** list the observed and standardized indices for longlines and tournaments, respectively. The spatial distribution of the data included most of the Northwest Atlantic for longlines, with lower spatial coverage and resolution in the tournament data (**Figure 2**). The observed trends in frequency of occurrence and mean CPUE showed a generally similar trend for the period of overlap (**Figure 3**).

The choice of standardization model differed between the two datasets; a negative binomial regression was selected for the longline dataset, while a delta-gamma model was selected for the tournament data. The divergence in model type was based on the observed frequency of blue marlin catches (**Figure 4**). While the negative binomial distribution appropriately modeled the mean and variance of observed longline catches, the range of catches during tournaments was great and not likely to be captured by the discrete distribution. For the tournaments, a delta-gamma model was selected, where the gamma distribution showed relatively good fit to the observed distribution of CPUE (**Figure 5**). The final models for both data types included year, area, and quarter as significant factors in addition to other covariates for the longline model. Model residuals are shown in **Figure 6**.

Results of the first model selection for both fisheries datasets indicated that area-quarter standardization accounted for more variation in CPUE than habitat or temperature covariates. Habitat, hooks per float, hook type, and day versus night were also determined to be significant covariates for pelagic longline catch rates. Accounting for the individual tournament effect was determined to be the best model for tournament data. When accounting for year-area-quarter and random tournament effects, the inclusion of habitat covariates did not improve the model. Possible explanations for the divergence in model behavior are that the fishing locations for observed longline sets are known with relatively high precision, while only the host port is known for tournaments. Therefore, there is much greater resolution in the assignment of habitat for longlines compared to recreational tournament fishing. Additionally, modeling individual tournaments as a random intercept accounted for much of the variation in catch rates that might be attributed to a combination of other factors, including habitat, location, seasonality, fishing methods, tournament regulations, prize categories, etc. In conclusion, the effect of other covariates was likely reduced when accounting for variation between individual tournaments. The strength in the repeated measures approach is that individual tournaments likely have a suite of factors that contribute to the difference in catch rates of blue marlin, and treating the tournament as a random effect can account for much of this variation in the absence of accurate covariate data.

The standardized index of abundance from the recreational tournament fishery showed a relatively stable trend for the early part of the time series, and a general increase since the 1990s (**Figure 7**). The longline index showed a similar trend for the period of overlap (**Figure 7**). Overall, the two indices showed good agreement for the period of overlap (**Figure 8**).

The change in regulation for the U.S. longline fleet to ban J-hooks is thought to influence the catch rates of marlins based on the results of experimental fishing studies. The observer dataset provided detailed information on gear configuration which allowed for the estimation of the hook type effect. Accounting for hook type was found to have an influence on the standardized index (**Figure 9**), indicating a more optimistic view of stock trend compared to models that did not account for the hook effect. In conclusion, the model standardization for longlines was extensive, as it included time/area, habitat, gear, and targeting covariates, resulting in standardized index that diverged considerably from the observed mean. For tournaments, it was important to account for the random variation amongst individual tournaments, and this approach likely reduced the influence of other covariates that effect tournament catch rates.

References

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Table 1. Change in Akaike Information Criteria (dAIC) with factors inclusion for U.S. longline observer data. The final model selected is shown in bold under selection test 4.

Selection	Model	dAIC	df
test1	year_area_quarter	0	40
	year_habitat	100	35
	year_sea_surface_temp	248	28
test2	year _area_quarter_habitat	0	49
	year_area_quarter_sea_temperature	441	42
	year_area_quarter_day/night	894	41
	year_ area_quarter _target	909	41
	year_ area_quarter _hooks/float	915	44
	year_ area_quarter _mainline_length	927	51
	year_ area_quarter _hookdepth	970	47
	year_ area_quarter_hooktype	973	44
	year_area_quarter	988	40
test3	year_area_quarter _habitat _day/night	0	50
	year_area_quarter _habitat_ hook/float	2	53
	year_area_quarter _habitat_ target	21	50
	year_area_quarter _habitat_ hooksize	35	66
	year_area_quarter _habitat_linelength	36	60
	year_area_quarter _habitat_hookdepth	59	56
	year_area_quarter _habitat_hooktype	71	53
	year_area_quarter _habitat	72	49
test4	year_area_quarter _habitat _day/night_hooks/float	0	54
	year_area_quarter _habitat _day/night_mainline	48	61
	year_area_quarter _habitat _day/night_target	69	51
	year_area_quarter _habitat _day/night_hookdepth	74	57
	year_area_quarter _habitat _day/night_hooktype	74	54
	year_area_quarter _habitat _day/night	79	50
test5	**year_area_quarter _habitat _day/night_hooks/float_hooktype**	0	58
	year_area_quarter _habitat _day/night_hooks/float	3	54

Table 2. Change in Akaike Information Criteria (dAIC) with factors inclusion for U.S. recreational tournament data. The final model selected is shown in bold under selection test 3.

Selection	Frequency of Occurrence GLM	dAIC	df
test1	year_tournament effect	0	45
	year_quarter_area	303	53
	year_temperature	651	46
	year_habitat	663	45
test2	year_area_quarter_tournament effect	0	54
	year_habitat_tournament effect	79	46
	year_tournament effect	85	45
test3	**year_area_quarter_tournament effect**	0	54
	year_area_quarter_tournament effect_habitat	1	55

Selection	Positive CPUE GLM	dAIC	df
test1	year_tournament effect	0	46
	year_quarter_area	690	54
	year_habitat	982	46
	year_temperature	1227	47
test2	year_area_quarter_tournament effect	0	55
	year_habitat_tournament effect	39	47
	year_tournament effect	90	46
test3	**year_area_quarter_tournament effect**	0	56
	year_area_quarter_tournament effect_habitat	1.4	55

Table 3. Standardized index of abundance for Atlantic blue marlin from the U.S. pelagic longline fishery.

Year	Obs_Frequency	Obs_CPUE	Index	Index_CV	95thLower_CL	95thUpper_CL
1993	0.17	1.18	1.24	0.17	0.89	1.72
1994	0.14	1.06	1.08	0.19	0.75	1.55
1995	0.17	1.30	1.11	0.17	0.80	1.54
1996	0.25	2.16	1.45	0.19	1.00	2.12
1997	0.21	1.63	1.15	0.19	0.79	1.68
1998	0.20	1.14	0.89	0.21	0.59	1.34
1999	0.20	1.32	1.09	0.19	0.75	1.59
2000	0.18	1.11	1.05	0.19	0.72	1.54
2001	0.06	0.37	0.50	0.22	0.33	0.77
2002	0.10	0.51	0.86	0.20	0.59	1.27
2003	0.06	0.33	0.58	0.20	0.39	0.86
2004	0.15	0.82	0.70	0.18	0.49	1.00
2005	0.18	1.05	1.20	0.18	0.84	1.72
2006	0.18	0.95	1.32	0.19	0.91	1.92
2007	0.17	1.10	1.12	0.18	0.79	1.59
2008	0.18	0.93	1.08	0.17	0.77	1.52
2009	0.20	1.00	1.09	0.17	0.78	1.53
2010	0.13	0.71	0.93	0.18	0.65	1.33
2011	0.20	1.14	1.16	0.18	0.82	1.64
2012	0.20	1.22	1.05	0.17	0.75	1.48
2013	0.14	0.77	0.73	0.17	0.52	1.03
2014	0.13	0.56	0.56	0.18	0.40	0.80
2015	0.15	1.05	0.95	0.18	0.67	1.35
2016	0.14	0.62	0.71	0.17	0.51	1.00

Table 4. Standardized index of abundance for Atlantic blue marlin from the U.S. recreational tournament fishery.

Year	Obs_Frequency	Obs_CPUE	Index	Index_CV	95thLower_CL	95thUpper_CL
1974	0.87	0.86	0.57	0.26	0.28	0.86
1975	0.90	0.95	0.60	0.30	0.25	0.95
1976	0.90	0.91	0.55	0.32	0.21	0.90
1977	0.90	0.95	0.68	0.31	0.26	1.10
1978	0.92	0.94	0.56	0.30	0.23	0.88
1979	0.87	0.95	0.55	0.40	0.12	0.97
1980	0.85	0.87	0.52	0.40	0.11	0.94
1981	0.94	1.10	0.64	0.28	0.28	0.99
1982	0.92	0.94	0.54	0.37	0.15	0.92
1983	0.88	1.04	0.54	0.39	0.12	0.95
1984	0.86	1.05	0.68	0.32	0.25	1.10
1985	0.92	1.09	0.66	0.29	0.29	1.03
1986	0.90	1.06	0.63	0.30	0.25	1.00
1987	0.81	1.03	0.65	0.36	0.19	1.11
1988	0.84	1.09	0.57	0.36	0.17	0.97
1989	0.82	0.86	0.55	0.35	0.17	0.93
1990	0.80	0.77	0.49	0.40	0.11	0.87
1991	0.76	0.81	0.54	0.44	0.08	1.00
1992	0.79	0.85	0.58	0.39	0.14	1.03
1993	0.85	1.23	0.63	0.37	0.17	1.08
1994	0.86	1.26	0.70	0.34	0.24	1.16
1995	0.80	1.32	0.82	0.35	0.25	1.38
1996	0.80	1.41	0.75	0.37	0.21	1.29
1997	0.81	1.13	0.70	0.34	0.23	1.17
1998	0.77	1.14	0.63	0.50	0.01	1.24
1999	0.82	1.54	0.99	0.33	0.35	1.63
2000	0.70	1.33	0.84	0.47	0.06	1.61
2001	0.69	1.01	0.53	0.57	-0.07	1.12
2002	0.67	1.07	0.59	0.49	0.02	1.17
2003	0.57	1.07	0.47	0.68	-0.16	1.11
2004	0.71	1.16	0.76	0.36	0.22	1.31
2005	0.71	1.19	0.75	0.38	0.19	1.32
2006	0.76	1.50	1.03	0.30	0.41	1.65
2007	0.72	1.14	0.76	0.35	0.24	1.28
2008	0.66	1.05	0.73	0.42	0.13	1.34
2009	0.66	1.18	0.67	0.51	0.00	1.34
2010	0.55	0.96	0.52	0.57	-0.06	1.10
2011	0.69	1.37	0.80	0.42	0.15	1.45
2012	0.69	1.59	1.32	0.35	0.43	2.21
2013	0.74	1.49	0.78	0.38	0.20	1.37
2014	0.67	0.83	0.59	0.54	-0.03	1.20
2015	0.77	1.65	1.01	0.34	0.34	1.69
2016	0.70	1.26	0.75	0.50	0.01	1.49

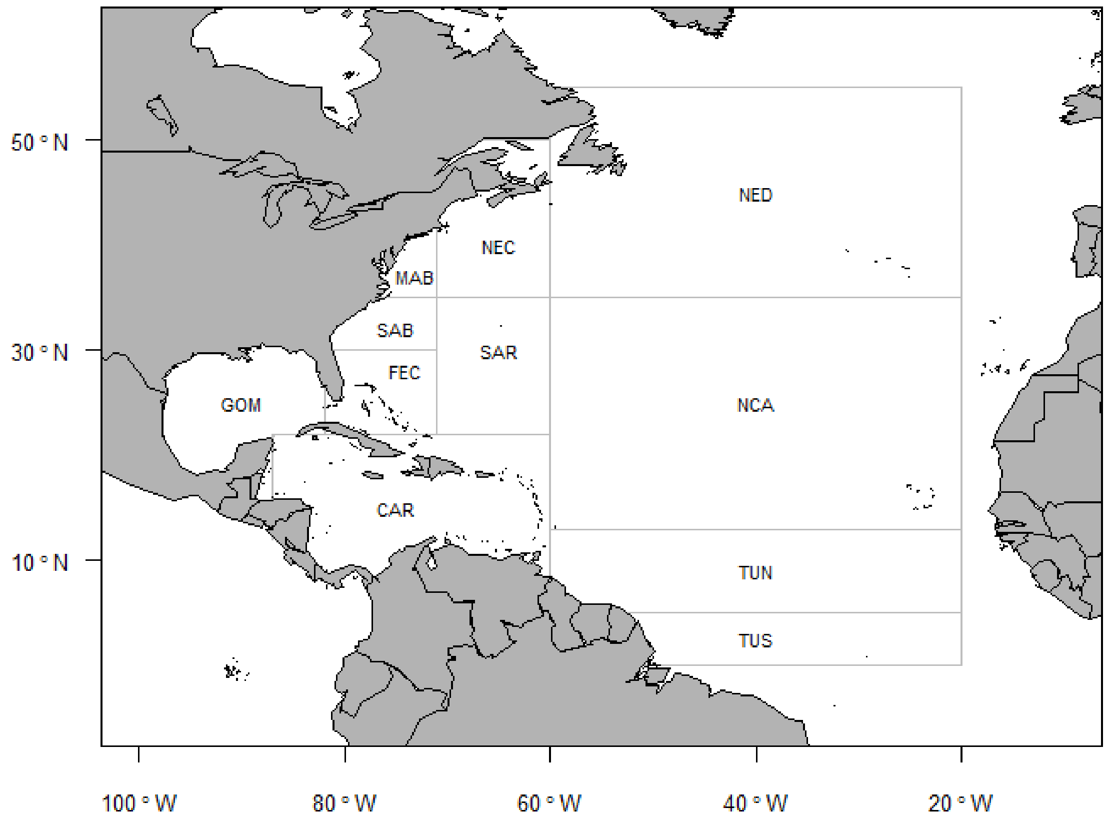
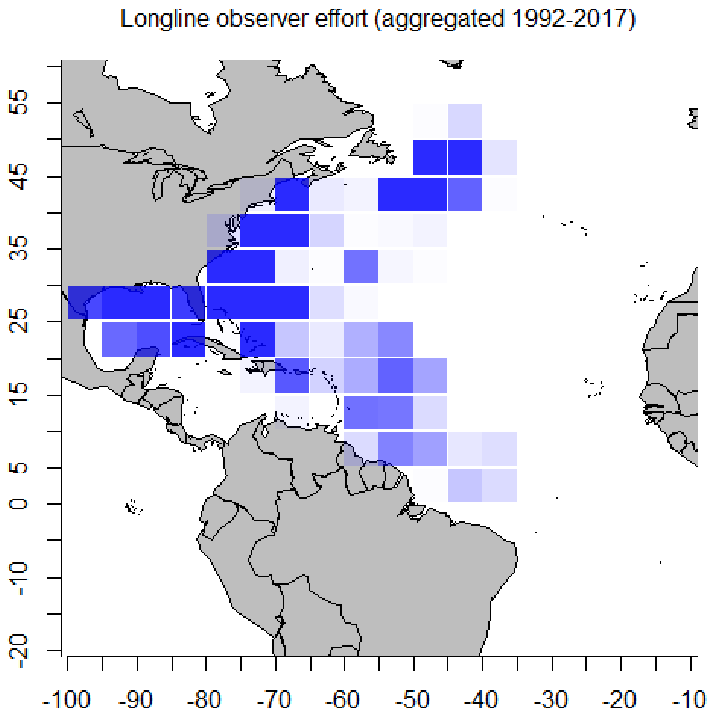


Figure 1. Geographical location classification of U.S. pelagic longline fleet operations used for analyses. *CAR* Caribbean, *GOM* Gulf of Mexico, *FEC* Florida East Coast, *SAB* South Atlantic Bight, *MAB* Mid-Atlantic Bight, *NEC* Northeast Coastal, *SAR* Sargasso, *NCA* North Central Atlantic, *TUN* Tuna North, and *TUS* Tuna South. The *NED* (Northeast Distant) sets are excluded from this analysis due to the Grand Banks closure.



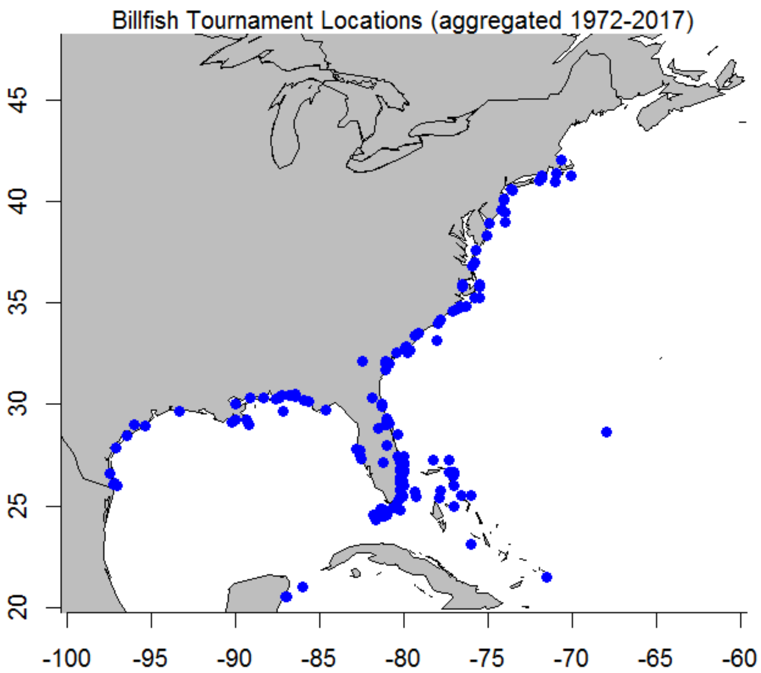


Figure 2. Geographical locations of fishing effort for the U.S. pelagic observers and recreational billfish tournaments.

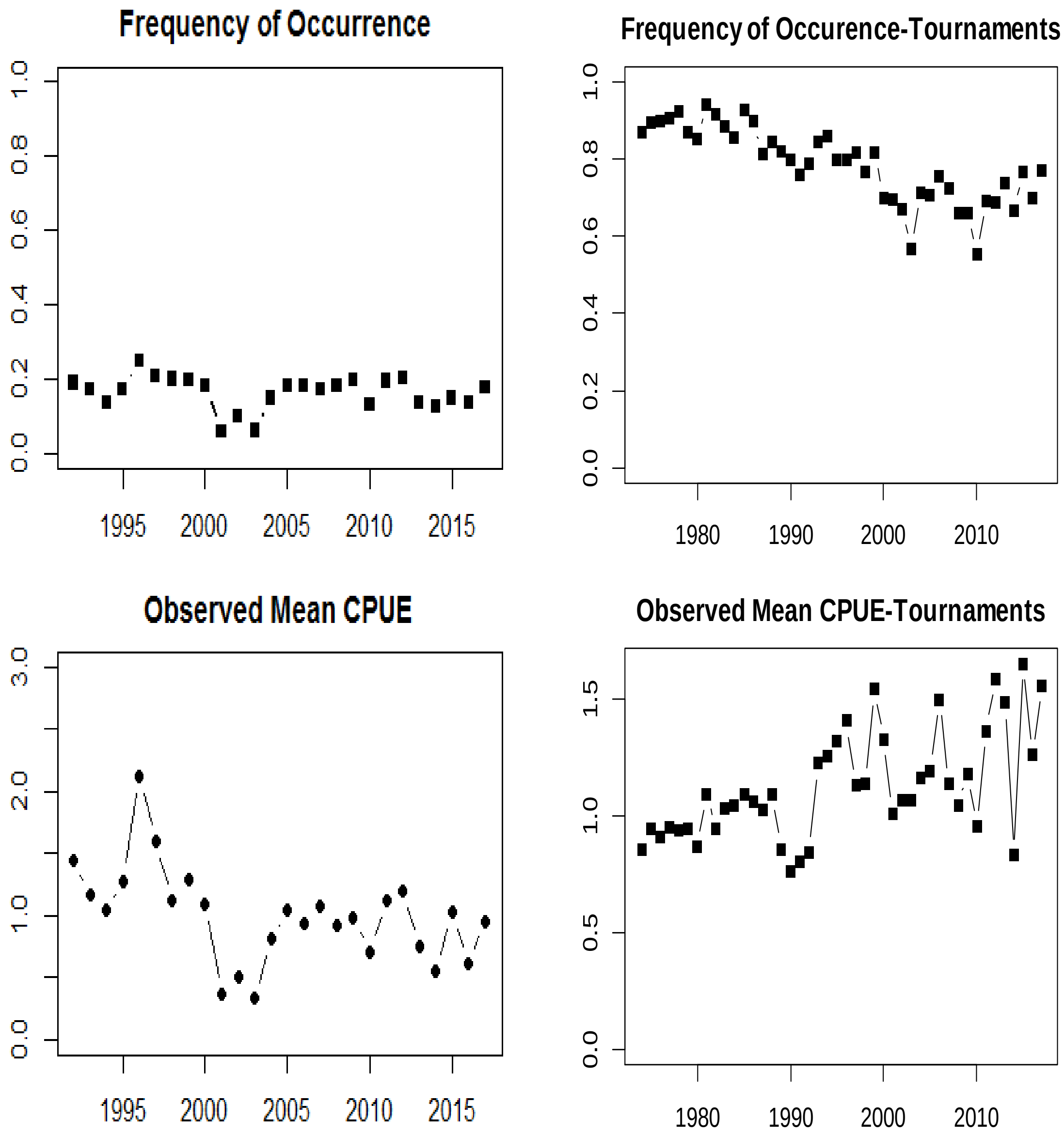


Figure 3. Observed frequency of occurrence (upper panels) and mean catch-per-unit-effort (lower panels) for the U.S. pelagic longline observer (left panels) and recreational tournament (right panels) datasets.

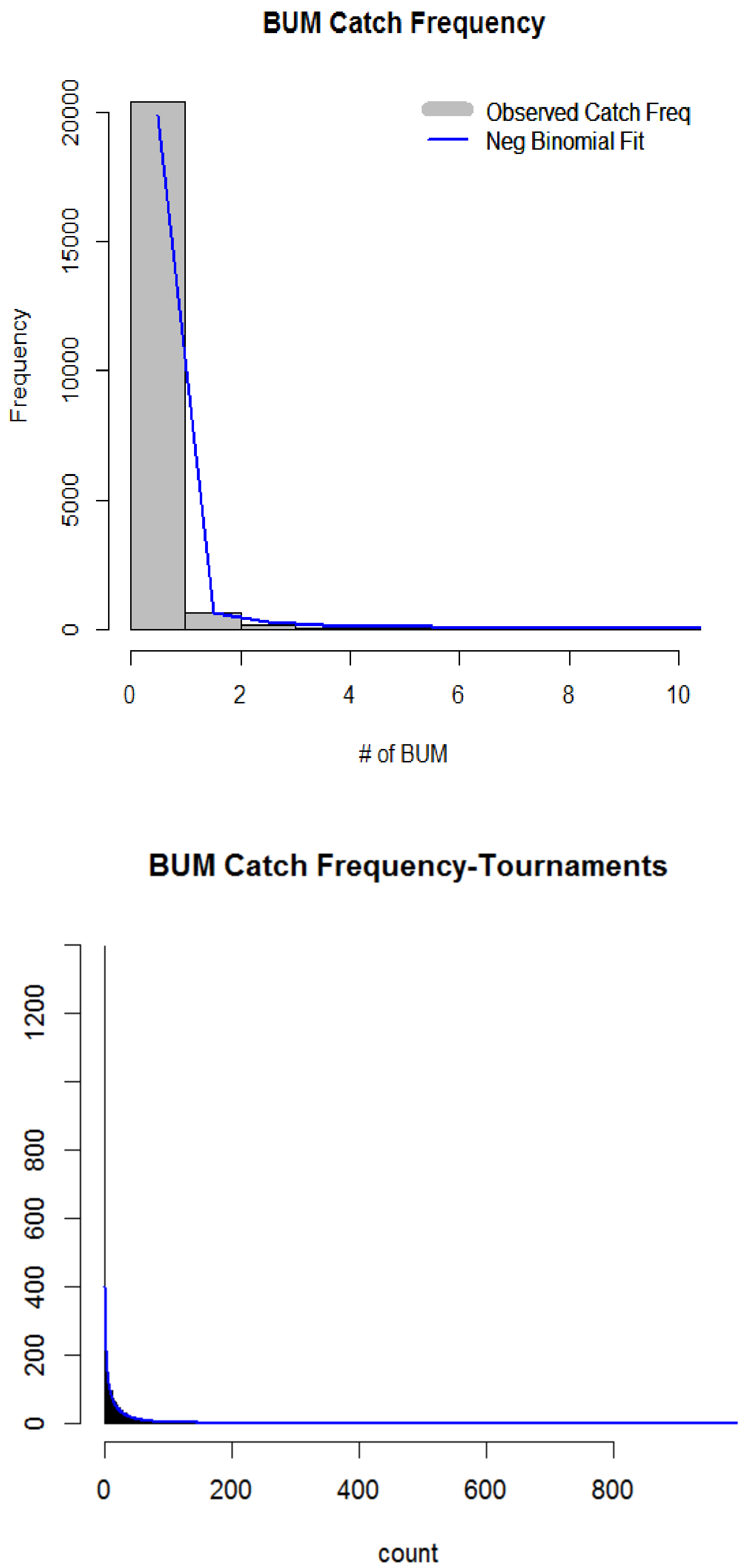


Figure 4. Negative binomial distribution fits to the number of blue marlin on longlines (upper panel) and recreational tournament catches (lower panel).

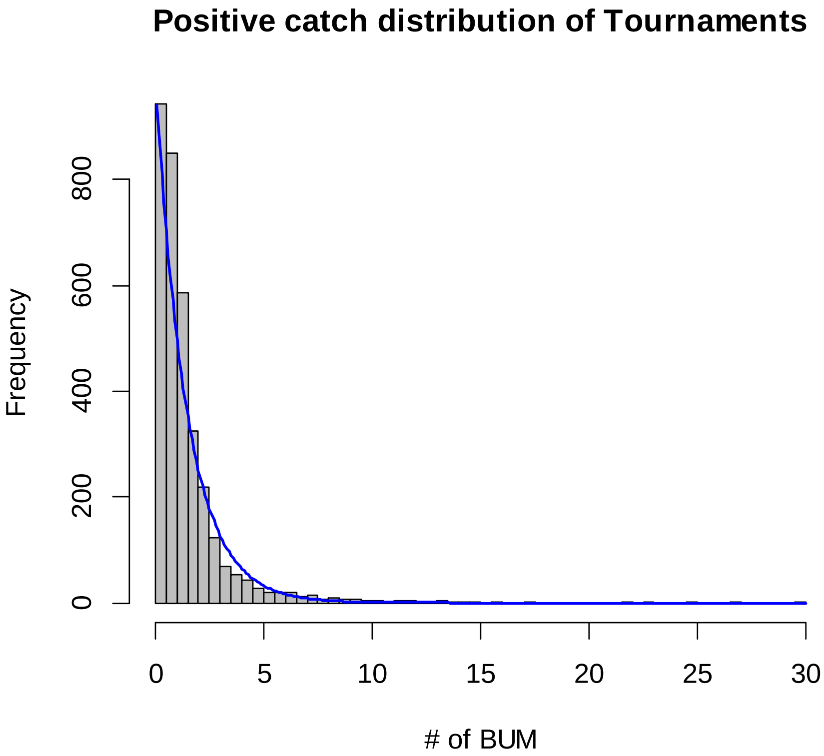
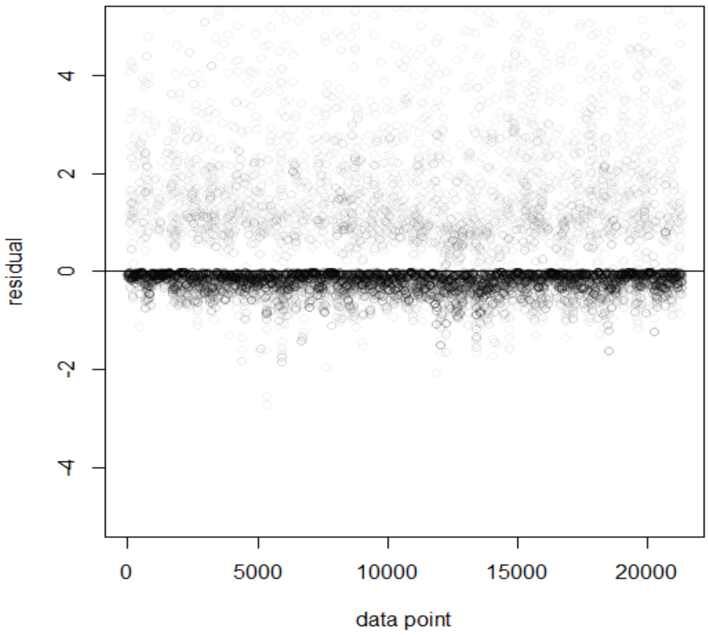


Figure 5. Gamma distribution fit to the CPUE of blue marlin on positive tournaments.



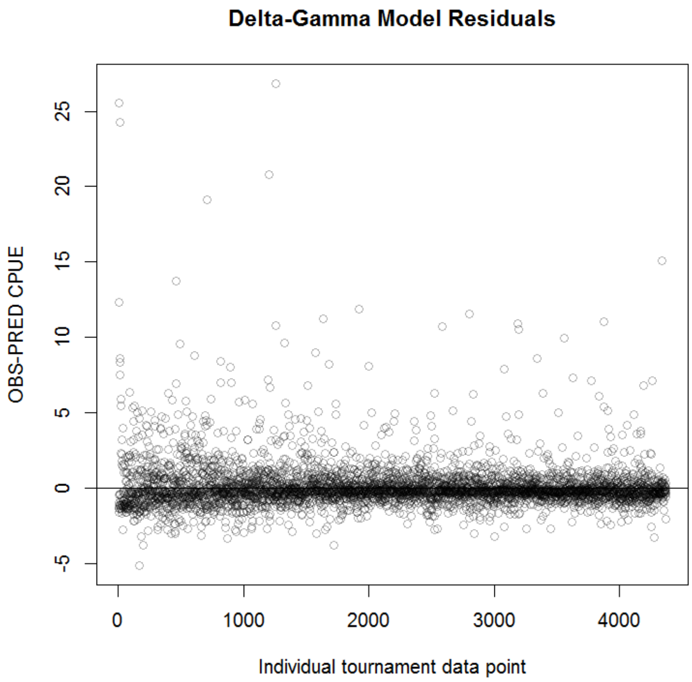
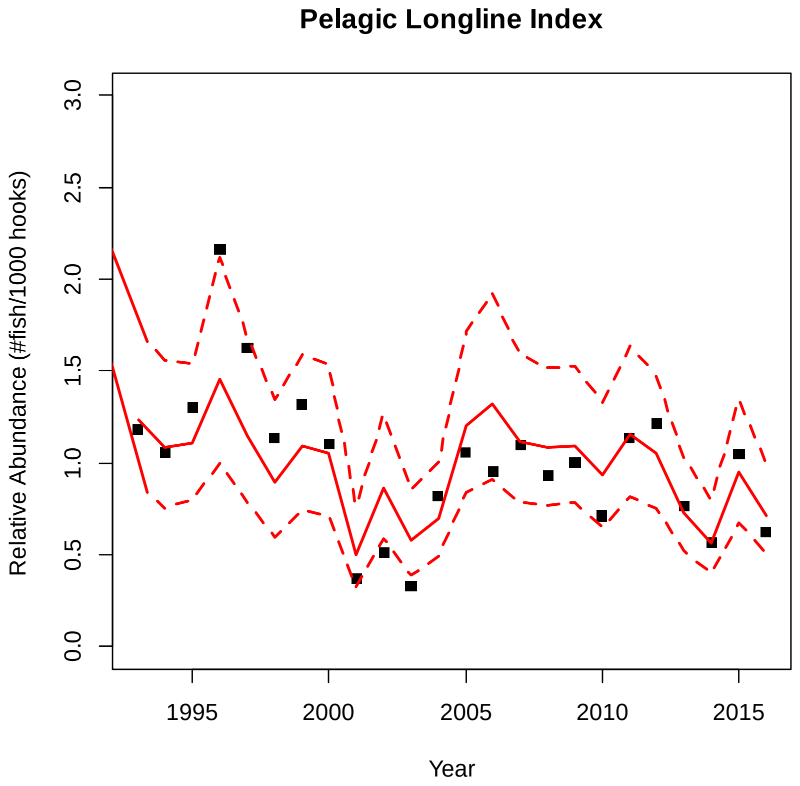


Figure 6. Model residuals for the negative binomial GLM of pelagic longline blue marlin CPUE (upper panel), and delta-gamma GLM of blue marlin tournament CPUE (lower panel).



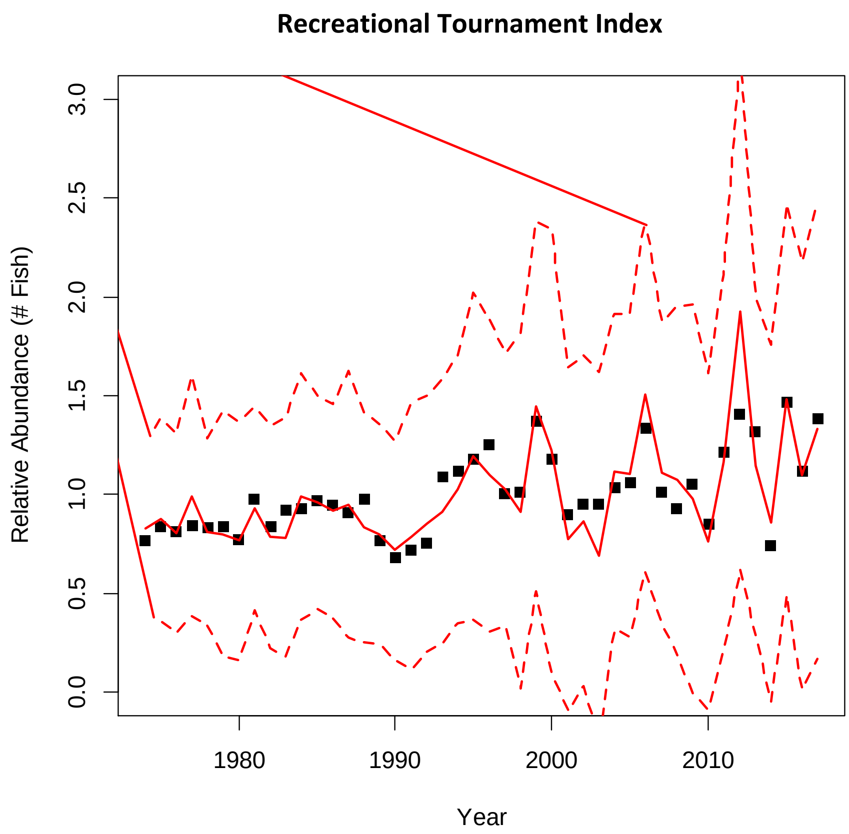


Figure 7. Standardized indices of abundance of blue marlin from the U.S. pelagic longline (upper panel) and blue marlin tournament fisheries (lower panel). Observed mean CPUE is shown as black points, the index is shown as a solid red line, and index 95th percentile confidence intervals are shown as dashed red lines.

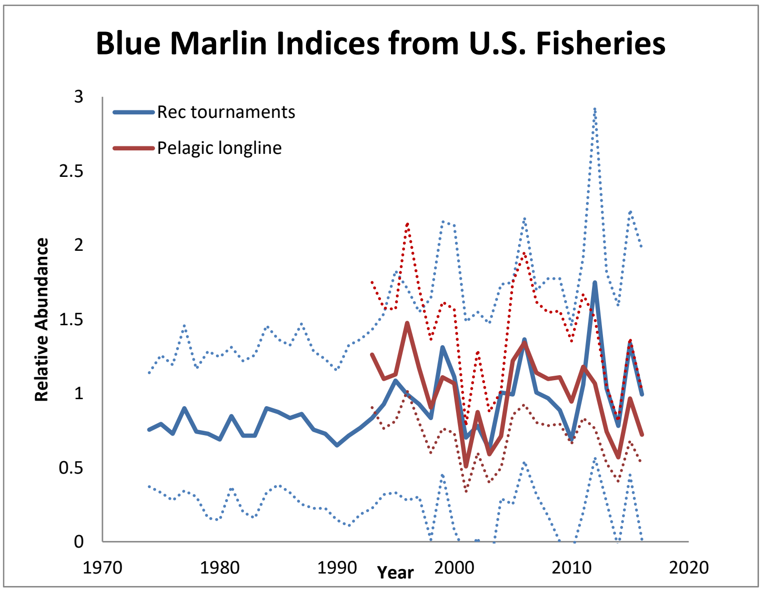


Figure 8. Comparison of standardized abundance indices of blue marlin on U.S. pelagic longline (red line) and recreational tournament (blue lines) fisheries.

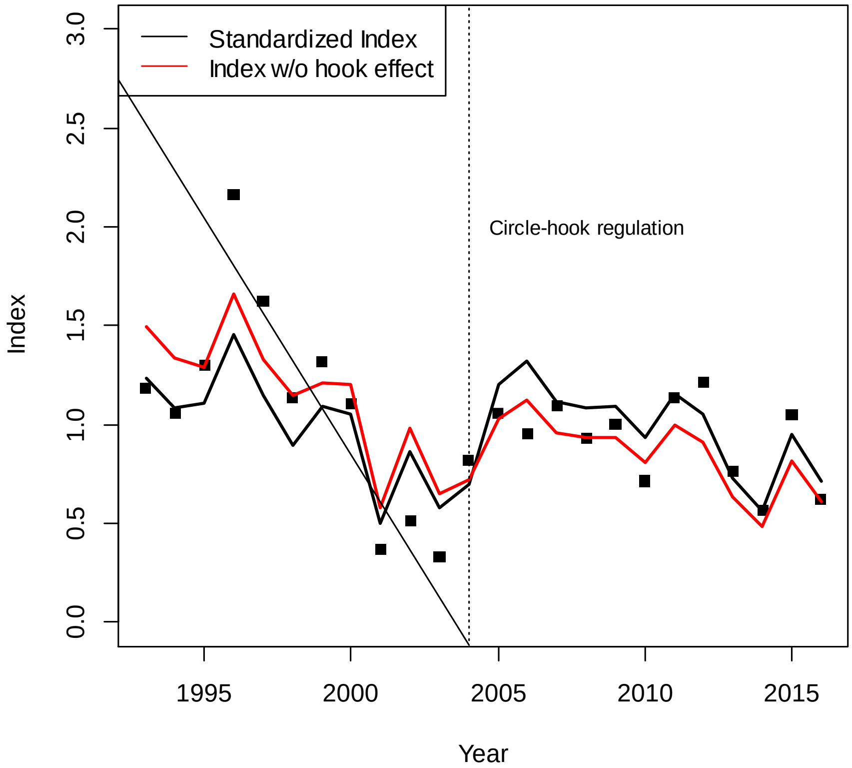


Figure 9. Effect of excluding hook type (red line) on the relative abundance index of blue marlin from U.S. pelagic longlines, compared to the selected model with hook type effect included (black line).