SCRS/2015/171 Collect. Vol. Sci. Pap. ICCAT, 72(7): 1729-1747 (2016)

AN INDEX OF ABUNDANCE OF BLUEFIN TUNA IN THE NORTHWEST ATLANTIC OCEAN FROM COMBINED CANADA-U.S. PELAGIC LONGLINE DATA

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SUMMARY

During a recent data workshop hosted by the Department of Fisheries and Oceans Canada, fishery scientists from Canada and the U.S. collaborated to evaluate pelagic longline fleet distributions and overlap in the Northwest Atlantic Ocean, and construct a combined Canada-U.S. standardized index of abundance for Atlantic bluefin tuna. Data from pelagic longline observer programs demonstrated considerable fleet spatial overlap and similar nominal catch rates in the Atlantic Ocean north of 40 degree latitude. A standardized index of abundance was constructed for the period 1992 to 2014 from the combined observer data, as both databases contained information on set location, fishery landings and discards, gear configuration and effort, and size composition. Environmental data were assigned to fisheries set level data to identify significant covariates of catch/catch rate. The collaboration produced an abundance index that covers a large portion of the range of the stock in the Northwest Atlantic, is more robust to fleet-wide changes in gear configuration and fleet expansion/contraction compared to fleet-specific indices, and provided size composition information for input into catch-at-size or integrated assessment models.

RÉSUMÉ

Au cours d'un récent atelier de données organisé par le ministère des Pêches et Océans du Canada, des halieutes du Canada et des États-Unis ont collaboré pour évaluer les distributions et le chevauchement des flottilles palangrières pélagiques dans l'océan Atlantique Nord-Ouest et élaborer un indice d'abondance standardisé combiné Canada-États-Unis pour le thon rouge de l'Atlantique. Les données provenant de programmes d'observateurs palangriers pélagiques ont démontré un chevauchement spatial considérable entre les flottilles et des taux de capture nominale similaires dans l'océan Atlantique au Nord de 40º de latitude. Un indice d'abondance standardisé a été élaboré pour la période 1992-2014 à partir des données d'observateurs combinées, étant donné que les deux bases de données contenaient des informations sur l'emplacement des opérations, les débarquements et les rejets des pêcheries, la configuration et l'effort des engins, ainsi que la composition par taille. Des données environnementales ont été assignées aux données halieutiques à des niveaux fixes pour identifier les covariables significatives de la capture/du taux de capture. La collaboration a produit un indice d'abondance qui couvre une grande partie de la gamme du stock de l'Atlantique Nord-Ouest, est plus solide face aux changements réalisés par l'ensemble des flottilles dans la configuration des engins et l'expansion/réduction des flottilles par rapport aux indices spécifiques aux flottilles, et celle-ci a fourni des informations sur la composition par taille aux fins de leur saisie dans des modèles intégrés de prise par taille ou d'évaluation.

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RESUMEN

Durante un reciente taller sobre datos acogido por el Departamento de Pesca y Océanos de Canadá, científicos pesqueros de Canadá y Estados Unidos colaboraron para evaluar las distribuciones de la flota de palangre pelágico y su solapamiento en el Atlántico noroccidental, así como para elaborar un índice de abundancia estandarizado combinado Canadá-Estados Unidos para el atún rojo del Atlántico. Los datos de los programas de observadores del palangre pelágico demostraron un considerable solapamiento espacial de las flotas y tasas de captura nominal similares en el Atlántico al norte de 40º de latitud. Se elaboró un índice de abundancia estandarizado para el periodo 1992-2014 a partir de los datos de observadores combinados, ya que ambas bases de datos contenían información sobre la ubicación de los lances, los desembarques y los descartes de la pesquería, la configuración del arte y el esfuerzo, así como sobre la composición por tallas. Se asignaron datos medioambientales a nivel de los datos de lances pesqueros para identificar las covariables importantes de la tasa de captura/captura. La colaboración tuvo como resultado un índices de abundancia que cubre una gran parte del rango del stock en el Atlántico noroccidental, es más robusto a cambios de toda la flota en la configuración del arte y a la expansión/reducción de la flota en comparación con índices específicos de la flota y proporcionaba información sobre la composición por tallas para introducirla en modelos de evaluación integrados o de captura por talla.

KEYWORDS

Atlantic bluefin tuna, Catch/effort, Environmental factors, Multivariate statistics, International waters

1. Introduction

The Department of Fisheries and Oceans Canada hosted a data workshop in St. Andrews, New Brunswick during July 13-17, 2015 to evaluate the feasibility of combining fleet effort, and Atlantic bluefin tuna catch and biological data from international fisheries and sampling programs operating in the West Atlantic Ocean. Scientists from Canada and the U.S. collaborated to accomplish multiple workshop objectives: (1) to evaluate pelagic longline fleet distributions and overlap, and construct a combined Canada-U.S. standardized index of abundance, (2) to assign environmental data to fisheries set level data, including a habitat foraging index provided by a cooperating EU scientists, and identify significant covariates of catch/catch rate, (3) to evaluate rod and reel/handline fishery distributions and overlap and construct a combined standardized index of abundance, and (4) to combine available electronic tagging data into a single database and evaluate data spatial coverage. The results of objectives one and two are presented in this paper, and the results of objective three and four are presented in separate documents. The three documents combined (Lauretta *et al*., 2016a (*in press*), Lauretta and Hanke, 2015 (*in press*), Hanke *et al.*, 2015 (*in press*) serve as a report of the findings of the data workshop.

2. Materials and methods

The collaboration initiated with a general discussion of the structure of pelagic longline data from the Canada and U.S. commercial logbooks and onboard observer programs. The commercial logbook data comprise records of fishing activity by fishermen who are required to report their fishing activity via logbooks submitted for each trip, while the observer data are recorded by trained observers onboard longline vessels that collect detailed information on set location, date, effort, gear configuration, environmental data, species, lengths, weights, biological samples, tag return information, and other information. The methods outlined in Lauretta *et al*., 2016b (*in press*) were applied to pelagic longline data from Canada and the U.S. to assign environmental covariates of sea-surface temperature, ocean depth, and seafloor gradient based on the detailed set-by-set level observations. A foraging habitat index value (Druon *et al*. in review) was also assigned to the detailed observations. Each dataset was then filtered to remove all fine-scale spatial, temporal, and fishing vessel information: the spatial resolution of observations was decreased from decimal degrees to 5x5 degree latitude-longitude squares and stock region (8-box regions, **Figure 1**); and temporal resolution was decreased from set date to month, season, and year. The logbook and observer datasets from the Canada and U.S. were then merged separately, following methods in Lauretta *et al*., 2016b (*in press*). The resulting merged datasets (logbook and observer) contained only the following fields: flag, gear, month, season, year, 5° latitude, 5° longitude, stock region, sea surface temperature, ocean depth, seafloor gradient, foraging habitat index, effort (hooks), and bluefin tuna catch. The observer dataset contained hook type as an additional field. Sample temporal (yearly) and spatial distributions (5x5 squares) were compared between flags for the datasets to determine overlap in sample coverage. Nominal catch rates were compared to examine trend agreement. The proportion of sets that caught bluefin tuna and annual catch histograms were examined to determine appropriate distribution assumptions of the standardization model.

Two generalized linear models (GLM) were developed for index standardization. The first assumed a delta-lognormal error structure and the second assumed a zero-inflated negative binomial error structure. The response variables in the delta lognormal model were presence of bluefin tuna (binomial distribution family, logit link function):

$$\Pr(Occurence) = \frac{1}{(1 + e^{-(\beta_0 + \beta_1 \cdot x_1 \cdots \beta_n \cdot x_n)})}$$

where
β_0= model intercept
β_1= variable coefficient
x_1= covariate variable
n = total number of covariate variables

and the $\log_e$-transformed catch-per-unit-effort (CPUE) of bluefin tuna on positive sets (Gaussian distribution family, identity link):

$$\log_e(CPUE) = \beta_0 + \beta_1 \cdot x_1 \cdots \beta_n \cdot x_n + \varepsilon$$

with similar notation for model intercept, coefficient and covariate variables as above and ε= error.

The response variable in the zero-inflated negative binomial model was catch of bluefin tuna (negative binomial distribution family with zero-inflation parameter, log link function, effort offset):

$$Catch_i \sim ZINB\left(\mu_i, \pi_i, k\right)$$

$$E(Catch_i) = \mu_i \cdot (1 - \pi_i) \text{ and } var(Catch_i) = \mu_i \cdot (1 - \pi_i) \cdot \left(1 + \pi_i \cdot \mu_i + \frac{\mu_i^2}{k}\right)$$

$$\mu_i = e^{\left(\beta_0 + \beta_1 \cdot x_1 \cdots \beta_n \cdot x_n\right)} \cdot Effort$$

where π_i = zero-inflation parameter and k = the variance scaling parameter, and similar notation for model intercept, coefficient and covariate variables as above.

The following factors were tested as covariates for each model: flag, month, year, 5° latitude, hook type, and sea surface temperature (2° gradient); and the following continuous variables were tested as covariates: ocean depth and seafloor gradient. Covariate selection for each model was based on deviance reduction (>2% model deviance reduction was the threshold for variable inclusion) and Akaike Information Criteria (AIC) (delta AIC greater than 4 was the threshold for variable inclusion). The same set of covariates selected for the binomial GLM were included in the zero-inflated negative binomial. This seemed like a reasonable assumption because of the large proportion of zero catches in the data, and because the zero-inflated negative binomial was run as an alternative model for the purpose of assessing index sensitivity to the error distribution assumption. The yearly least squares means were estimated for the delta-lognormal and zero-inflated negative binomial models, along with 95% confidence intervals of the means. Index and confidence intervals for the delta-lognormal model were calculated following Walter *et al*., 2016 (*in press*) using the Goodman exact estimator for combined variance.

Size (U.S.) and weight (Canada) observations of catches and discards were compiled from observer data into a single database. U.S. observer measurements were recorded as straight fork length in cm, and Canadian observer measurements were converted to straight fork length from round weight in kg using the monthly length-weight relationships for western bluefin tuna (Rodriguez-Marin *et al*. in review). Annual length frequency histograms were generated to compare size structure across years.

3. Results

Observed catch rates demonstrated similar trends between the Canada observer, commercial logbook, and U.S. observer data (**Figure 2**); however, U.S. commercial logbook data showed a lower catch rate and effort in recent years for areas north of 40 degree latitude and south of 50 degree latitude where the fleets overlapped in fishing effort (**Figure 3**). The observer data were selected for index standardization due to consistency in trend between fleets, relatively good spatial coverage and overlap of fishing effort, comparable sample sizes in areas and years of fleet overlap (**Figure 4**), accounting of fleet landings and discards of bluefin tuna, high resolution latitude and longitude information for each set from which environmental covariates could be assigned, description of gear configuration, and measurements of fish size/weight composition. The commercial logbook data were excluded from index standardization due to potential bias in the U.S. data from catch restrictions and under-reporting of bluefin discards.

The spatial domain of the observer index included a large portion of the foraging area of the western stock, restricted to the Atlantic Ocean east of -80°W longitude and north of 20°N latitude. Samples west of -80°W longitude were excluded from the model, so that the resulting index represented a complimentary index to the existing spawner abundance index from longline samples in the Gulf of Mexico. The areas south of 20°N latitude were excluded because no observations of bluefin tuna were documented in those areas. The temporal range of the index was 1992 to 2014, of which U.S. data spanned the period, and Canadian data were available for the period 2002 to 2014.

A bluefin tuna foraging habitat index (Druon *et al*. in review) was assigned to approximately 21% of the observer sets. The other 79% of samples were missing values due to cloud cover. Therefore, a test of foraging habitat quality as a covariate of bluefin occurrence, catch, or catch rate was not able to be conducted at the current habitat index resolution.

The observed frequency of occurrence of bluefin tuna (**Figure 5**) varied considerably across years, months, latitude, and sea surface temperatures. Noted trends included higher frequency of occurrence during years 2006, 2009 to 2011, peaks in June and between latitude 50 to 55, and a steady decrease with increased sea surface temperature. Differences in the frequency of occurrence between flag and hook type were also noted. Comparison of the observed catch rates on positive sets showed similar factor effects (**Figure 6**); however, median and other percentiles of catch rate did not indicate a difference for flag or hook type.

Model selection for the delta-lognormal GLM resulted in inclusion of year, month, and sea surface temperature (2° bins) as significant factors in both the probability of bluefin tuna occurrence binomial GLM and $\log_e$-transformed catch rate normal GLM (**Tables 1 and 2**). In addition, latitude (5° cell) was included as a factor in the probability of occurrence GLM. Model predictions showed general agreement with the observed frequency of occurrence of bluefin tuna (**Figure 7**). The standardized index trend showed a period of relatively low probability of occurrence (ranged 4 to 10 % occurrence) between 1992 and 2003, a period of steadily increasing probability between 2001 and 2009 (increased 9 to 22% occurrence), and a period of higher probability between 2009 and 2014 (ranged 15 to 20% occurrence) (**Figure 7**). The normal probability density model showed good fit for a few select years (e.g., 2014); however, the observed annual distributions of $\log_e$-transformed catch rates demonstrated considerable skew for several years (**Figure 8**). The delta-lognormal predicted yearly mean index trend was similar to the probability of occurrence model, with the exception of a peak index value in 1995 (**Figure 9**). In comparison to the observed nominal CPUE for 1995, the standardized index from the predicted least-square mean was considerable lower. The zero-inflated negative binomial GLM resulted in a similar index as the delta-lognormal GLM (**Figure 10**); however, the confidence intervals were considerably larger under the zero-inflated negative binomial error assumption. In comparison, the yearly least-square mean coefficient of variation ranged between 0.14 and 0.51 for the delta-lognormal model versus a range of 0.57 to 0.70 for the zero-inflated negative binomial model. A statistical comparison between the two models could not be made due to the difference in sample treatment of presence/absence and positive catch rate as separate response variables in the delta-lognormal GLMs (i.e. positive sets are modeled twice) versus catch as the predicted variable in the zero-inflated negative binomial GLM.

The size of bluefin tuna captured on longlines ranged from 31 to 370 cm straight fork length, with the majority of fish between 120 and 300 cm (**Figure 11**). The number of measurements ranged from low samples in select years (<100 measurements per year in 1996 to 2000) to high samples during some periods (>400 measurements per year in 2006 to 2012). As a generalization, longline catches were comprised of fish greater than 120 cm straight fork length. Given the observed range of sizes and the current growth curve for western bluefin tuna, the index is expected to be representative of fish 4 years of age and older (assuming a plus group less than 35 years).

4. Discussion

The observer programs for Canada and the U.S. recorded similar information for pelagic longline sets, demonstrated considerable sampling overlap in the Northwest Atlantic between latitudes 40° and 50°N, and showed similar nominal trends within the region and for years of overlap. The commercial logbook observed catch rates for Canada were similar to the observer measured catch rates; however, the U.S. commercial logbook data diverged considerably from the other data sources. This divergence was thought to be a result of under-reporting of discarded bluefin, as the U.S. longline fisheries are limited on the number of bluefin tuna that can be retained and fish are frequently released versus brought onboard the vessels (Keene pers. comm.), which could result in hyperstability in the abundance index. The observer data is better suited for an index of abundance of bluefin tuna, as all captured fish are recorded and measured, along with detailed information on the date, location, gear configuration, tag recoveries, and other information. The spatial locations of samples demonstrated changes in fleet distributions across years. Combining the two datasets resulted in greater spatial coverage, as well as increased robustness to changes in individual fleet distribution. Information on the size composition of captured fish provided the benefit of informing the reference age of the index for application to the current assessment framework, as well as data input into catch-at-size or integrated models.

The Gulf of Mexico observer samples were excluded from the analysis, despite the fact that the U.S. fleet has 50% observer coverage in the region. This decision was made because (1) data from the U.S. fleet only are available from that region (although Mexico has an extensive observer program for longline vessels in the Gulf of Mexico and a similar collaboration could be beneficial for that region), (2) an index of spawner abundance in the Gulf of Mexico from U.S. longline data during the period when fish are likely aggregated for spawning is currently used in the stock assessment, (3) the habitat foraging model was expected to be most applicable to the Atlantic Ocean where fish are known to migrate after spawning to forage (Block *et al*. 2005), and (4) the Canadian fisheries primarily operate during the period when fish are available after migrating north in early summer through fall. The index developed through the Canada-U.S. collaboration therefore represents a compliment to the Gulf of Mexico spawner index, as data applied to each index are mutually exclusive. Furthermore, bluefin tuna catch regulations in the Gulf of Mexico have become increasingly restrictive (e.g., closed areas, gear restrictions, catch limits, etc.) and are likely to greatly bias the Gulf of Mexico spawner index; therefore, the development of an observer-based index that covers the foraging grounds in the Northwest Atlantic Ocean was timely.

The methods outlined in Lauretta *et al*., 2016b (*in press*) were successfully applied to both datasets, and the approach proved to be an achievable path forward for data sharing and collaboration. Environmental covariates are assigned to each sample based on the detailed set level information that are available to authorized representatives of each nation, but the data released for the standardization process are filtered to avoid sharing the detailed spatial, temporal, and vessel specific information that is otherwise considered confidential. Thus we now believe we have a method for integrated catch rate analyses across multiple international fleets that avoids violating the confidentiality restrictions imposed by various nations. We recommend extending the analysis to other species, including yellowfin tuna, albacore, and swordfish, as well as welcome collaboration amongst other fishing nations with observer coverage of longline vessels operating in the Atlantic Ocean or Gulf of Mexico.

Although we were not successful at evaluating foraging habitat as a covariate of bluefin tuna occurrence, catch rate, or catch because of missing habitat suitability index values for the majority of samples, further collaborations in this regard may produce better results. For example, if we can determine the appropriate strata resolution that allows for the assignment of an index value to a large proportion of samples, we can then evaluate the effect of habitat suitability as a covariate of catch metrics. The significance of sea surface temperature as a covariate of bluefin tuna probability of occurrence and catch rate indicated the influence of habitat in the catch statistics. This is an area of research that deserves further evaluation, particularly since ocean conditions are predicted to change and result in shifts in stock distribution. The increased spatial coverage of data resulting from this collaboration greatly strengthens the ability to detect the effect of environmental changes on stock migration and fishery catches.

Literature cited

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Table 1. Model selection criteria for the delta-lognormal probability of bluefin occurrence standardization model.

Model	LogLike	Deviance	DevReduction	%Reduction	df	dAIC
Intercept only	-4265	8530			1	471
SST	-4021	8041	489	5.7	10	0
Lat	-4077	8154	377	4.4	7	106
Month	-4072	8144	386	4.5	12	107
Flag	-4128	8256	274	3.2	2	199
Year	-4174	8348	182	2.1	23	333
HookType	-4214	8428	102	1.2	2	371
Gradient	-4255	8510	20	0.2	2	453
Depth	-4263	8527	3	0.0	2	470
SST	-4021	8041			10	520
SST+Month	-3750	7499	542	6.7	21	0
SST+Lat	-3860	7721	321	4.0	16	211
SST+Year	-3856	7711	330	4.1	32	234
SST+Flag	-3967	7933	108	1.3	11	414
SST+HookType	-3968	7936	105	1.3	11	417
SST+Gradient	-4015	8030	11	0.1	11	511
SST+Depth	-4017	8034	7	0.1	11	515
SST+Month	-3750	7499			21	260.8
SST+Month+Lat	-3613	7226	273	3.6	27	0
SST+Month+Year	-3605	7210	289	3.9	43	16
SST+Month+HookType	-3686	7372	127	1.7	22	136
SST+Month+Flag	-3696	7391	108	1.4	22	155
SST+Month+Gradient	-3730	7460	39	0.5	22	224
SST+Month+Depth	-3741	7483	17	0.2	22	246
SST+Month+Lat	-3613	7226			27	207
SST+Month+Lat+Year	-3488	6976	251	3.5	49	0
SST+Month+Lat+HookType	-3561	7122	104	1.4	28	105
SST+Month+Lat+Flag	-3573	7147	80	1.1	28	129
SST+Month+Lat+Depth	-3588	7176	50	0.7	28	159
SST+Month+Lat+Gradient	-3600	7200	27	0.4	28	182
SST+Month+Lat+Year	-3488	6976			49	40
SST+Month+Lat+Year+Flag	-3467	6933	42	0.6	50	0
SST+Month+Lat+Year+Depth	-3475	6950	26	0.4	50	17
SST+Month+Lat+Year+Gradient	-3481	6962	14	0.2	50	29
SST+Month+Lat+Year+HookType	-3485	6970	6	0.1	50	36

Table 2. Model selection criteria for the delta-lognormal catch rate on positive sets standardization model.

Model	LogLike	Deviance	DevReduction	%Reduction	df	dAIC
Intercept only	-1792	3584			2	78
Year	-1731	3462	122	3.4	24	0
SST	-1750	3500	85	2.4	11	12
Depth	-1748	3497	88	2.4	14	15
Month	-1752	3504	80	2.2	13	20
Lat	-1761	3522	62	1.7	8	28
HookType	-1766	3533	52	1.4	3	29
Gradient	-1790	3579	5	0.1	3	75
Flag	-1791	3582	2	0.1	3	78
Year	-1731	3462			24	81
Year+SST	-1682	3363	99	2.9	33	0
Year+Depth	-1690	3380	82	2.4	36	23
Year+Lat	-1699	3397	65	1.9	30	28
Year+Month	-1696	3393	69	2.0	35	34
Year+HookType	-1707	3414	48	1.4	25	35
Year+Gradient	-1727	3455	7	0.2	25	76
Year+Flag	-1731	3461	1	0.0	25	82
Year+SST	-1682	3363			33	50
Year+SST+Month	-1646	3291	72	2.1	44	0
Year+SST+HookType	-1658	3316	48	1.4	34	4
Year+SST+Lat	-1658	3317	47	1.4	39	15
Year+SST+Depth	-1655	3310	53	1.6	45	21
Year+SST+Flag	-1669	3339	25	0.7	34	27
Year+SST+Gradient	-1680	3359	4	0.1	34	48
Year+SST+Month	-1646	3291			44	55
Year+SST+Month+Depth	-1617	3234	57	1.7	45	0
Year+SST+Month+HookType	-1620	3241	51	1.5	45	6
Year+SST+Month+Lat	-1624	3249	43	1.3	50	25
Year+SST+Month+Flag	-1636	3272	19	0.6	45	38
Year+SST+Month+Gradient	-1640	3280	11	0.3	45	46

Table 3. Observed catch rates and standardized index of abundance of bluefin tuna in the Northwest Atlantic Ocean.

Year	*n*	*ObsFreq*	*ObsCPUE*	*PredFreq*	*Index*	*CV*	*95%LowerCI*	*95%UpperCI*
1992	234	0.11	1.18	0.06	0.59	0.28	0.34	1.03
1993	483	0.08	0.32	0.07	0.65	0.23	0.41	1.02
1994	393	0.08	0.36	0.06	0.69	0.25	0.42	1.13
1995	323	0.05	0.14	0.05	0.56	0.33	0.29	1.06
1996	106	0.04	0.12	0.07	1.21	0.64	0.37	3.91
1997	213	0.09	0.18	0.08	0.74	0.31	0.41	1.36
1998	167	0.10	0.27	0.11	1.14	0.34	0.59	2.20
1999	181	0.11	0.44	0.08	0.77	0.33	0.41	1.47
2000	229	0.08	0.29	0.07	0.69	0.31	0.38	1.26
2001	834	0.06	0.11	0.03	0.22	0.22	0.15	0.34
2002	1025	0.12	0.31	0.07	0.46	0.15	0.34	0.62
2003	954	0.08	0.30	0.06	0.48	0.18	0.34	0.69
2004	445	0.12	0.44	0.08	0.57	0.20	0.38	0.85
2005	493	0.09	0.21	0.09	0.60	0.22	0.39	0.93
2006	442	0.16	0.69	0.12	1.26	0.18	0.88	1.81
2007	385	0.10	0.67	0.10	1.30	0.22	0.84	2.02
2008	420	0.13	0.35	0.14	1.17	0.19	0.80	1.71
2009	651	0.18	1.70	0.19	2.10	0.14	1.58	2.79
2010	615	0.18	0.79	0.15	1.74	0.15	1.29	2.35
2011	736	0.17	1.07	0.16	1.72	0.14	1.29	2.29
2012	640	0.14	0.47	0.14	1.44	0.16	1.05	1.98
2013	856	0.11	0.27	0.15	1.59	0.16	1.16	2.17
2014	799	0.12	0.37	0.13	1.29	0.16	0.95	1.77

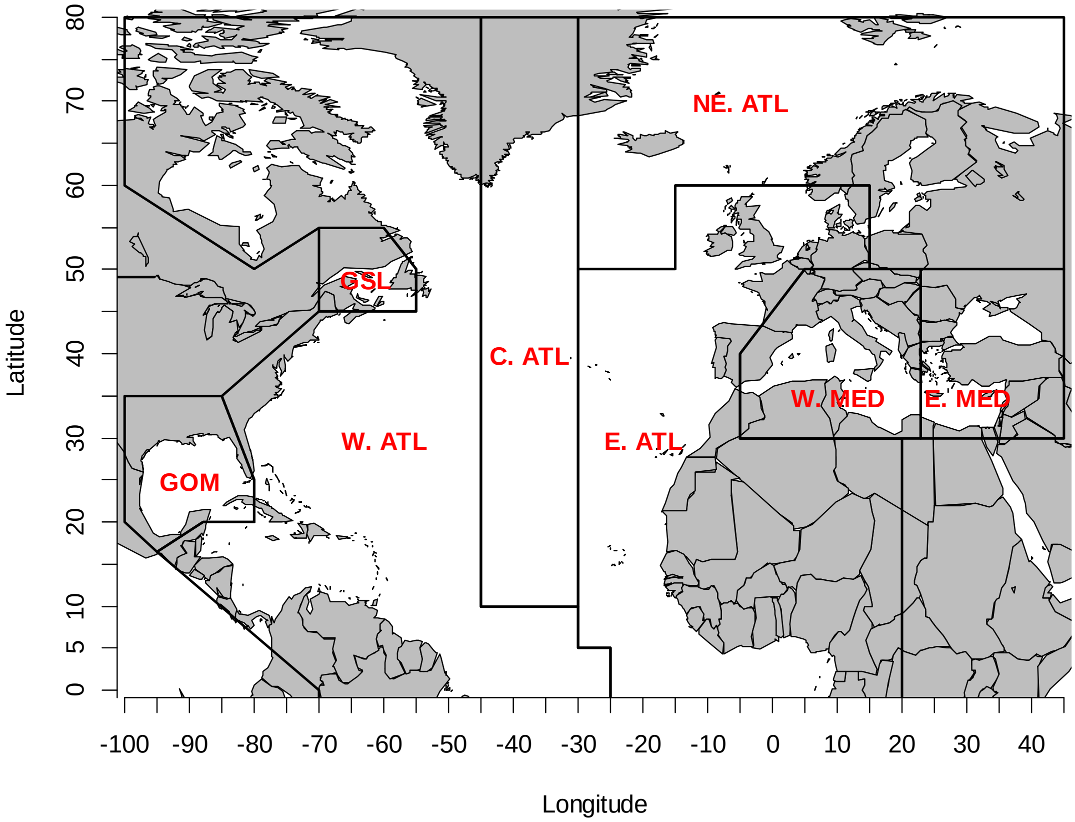

Figure 1. Atlantic bluefin tuna stock regions.

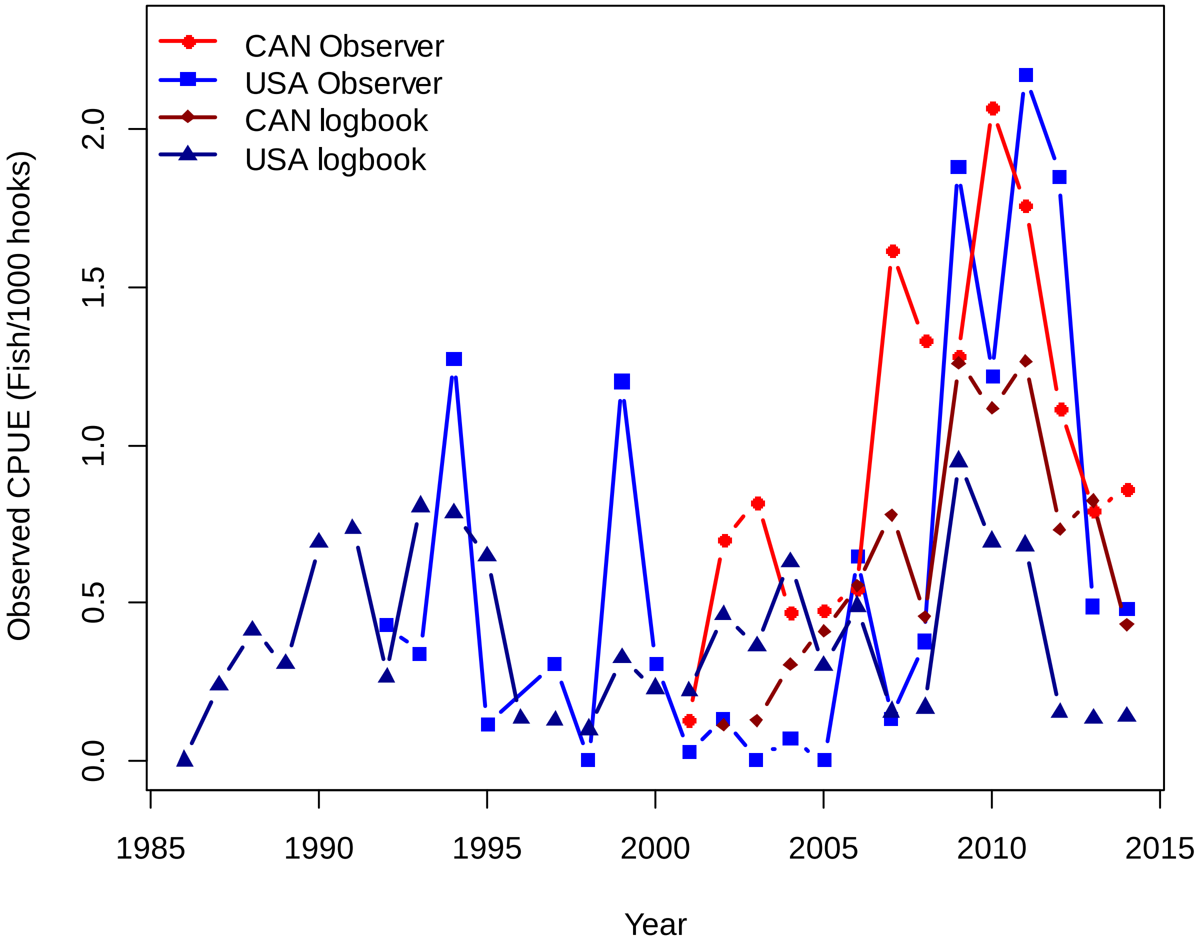

Figure 2. Catch rate trend comparison between Canada and U.S. observer and commercial logbook data collected in the Northwest Atlantic North of 40 degrees latitude.

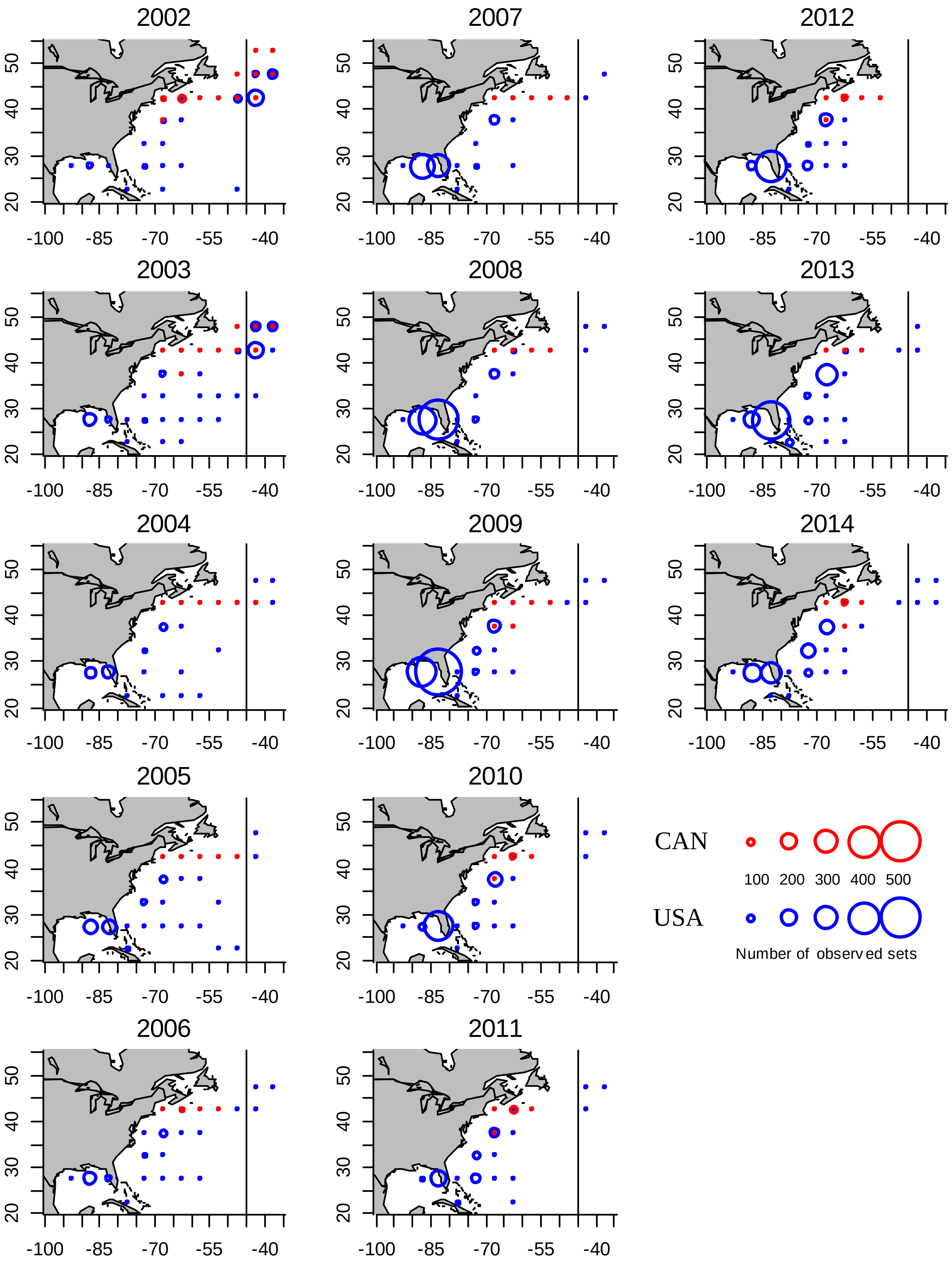

Figure 3. Spatial distribution (5x5 grid) and fleet overlap (CAN=red, USA=blue) of longline observer sampling.

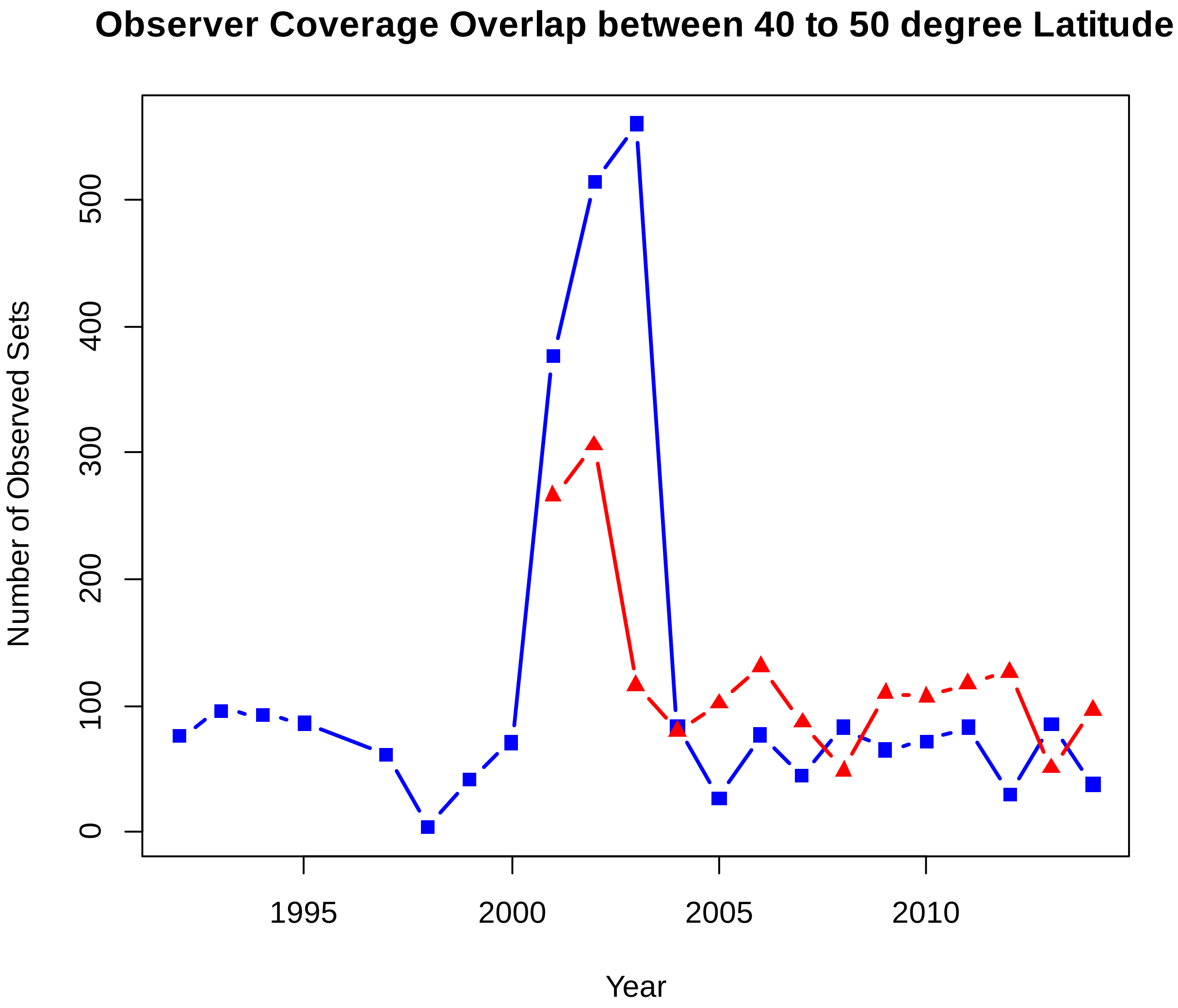

Figure 4. Overlap in onboard observer coverage of the United States (blue squares) and Canadian (red triangles) pelagic longline observer programs in the West Atlantic Ocean.

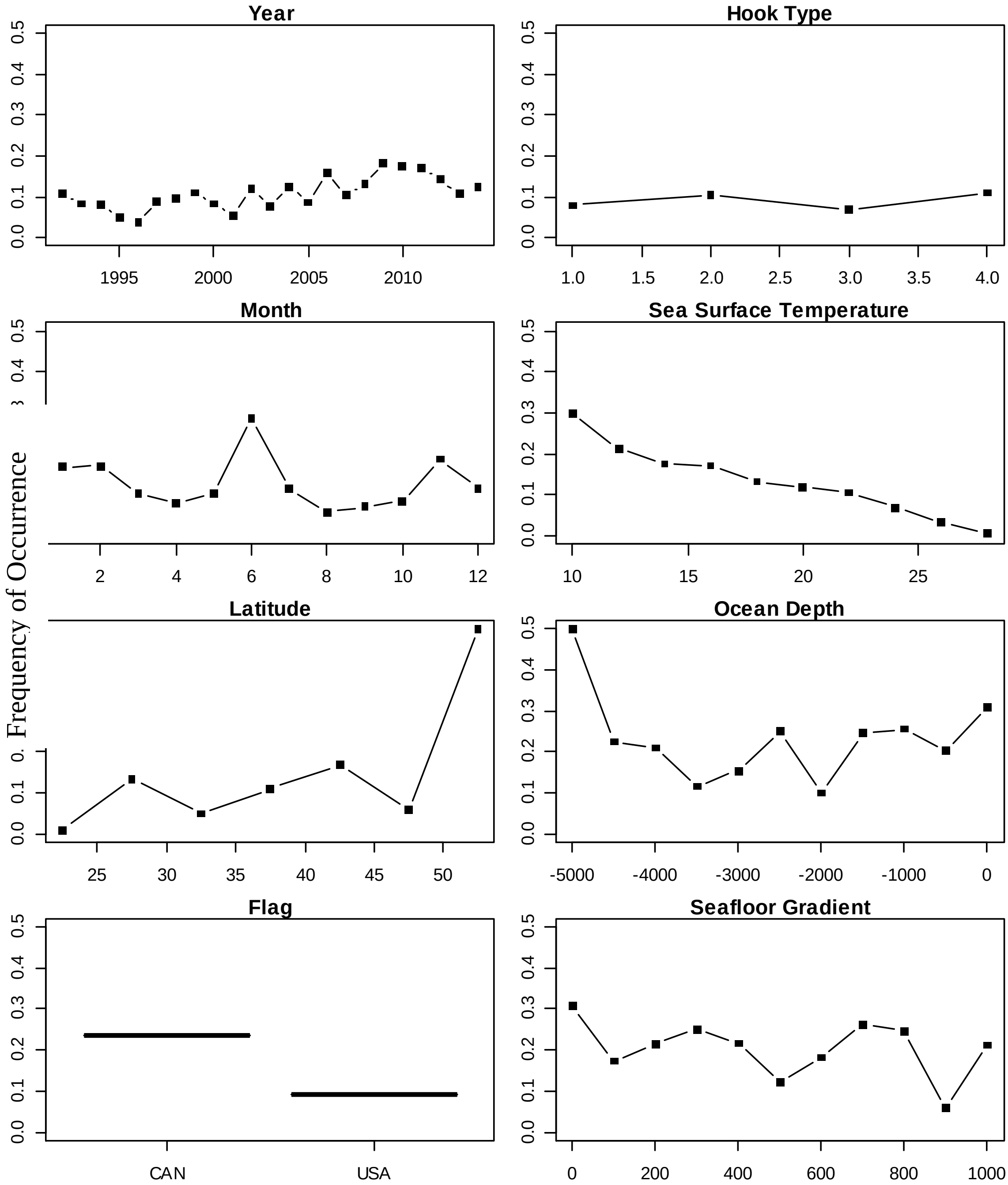

Figure 5. Observed frequency of occurrence of bluefin tuna compared across factor and continuous variables.

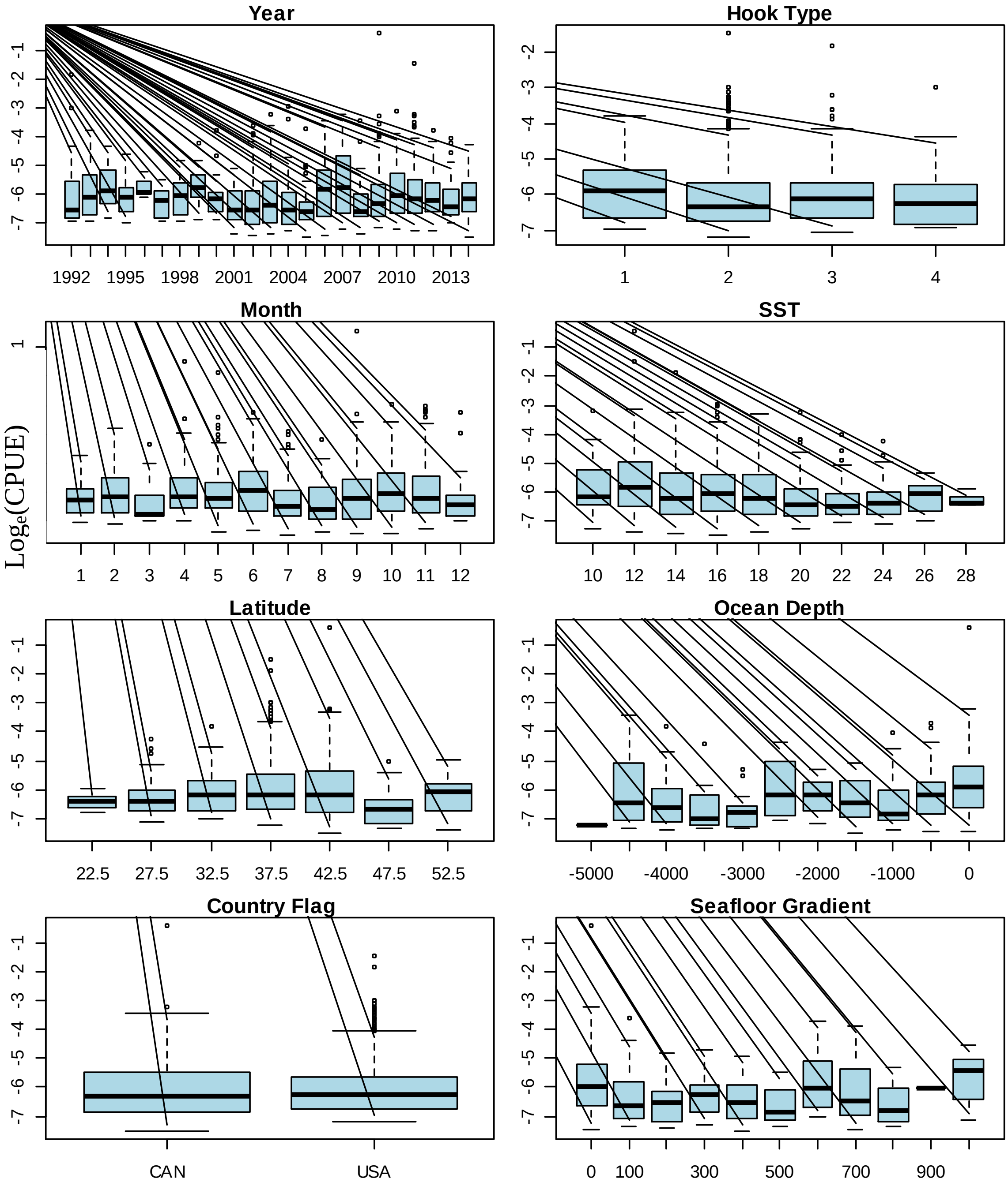

Figure 6. Observed $\log_e$-transformed mean CPUE by factor and continuous variables.

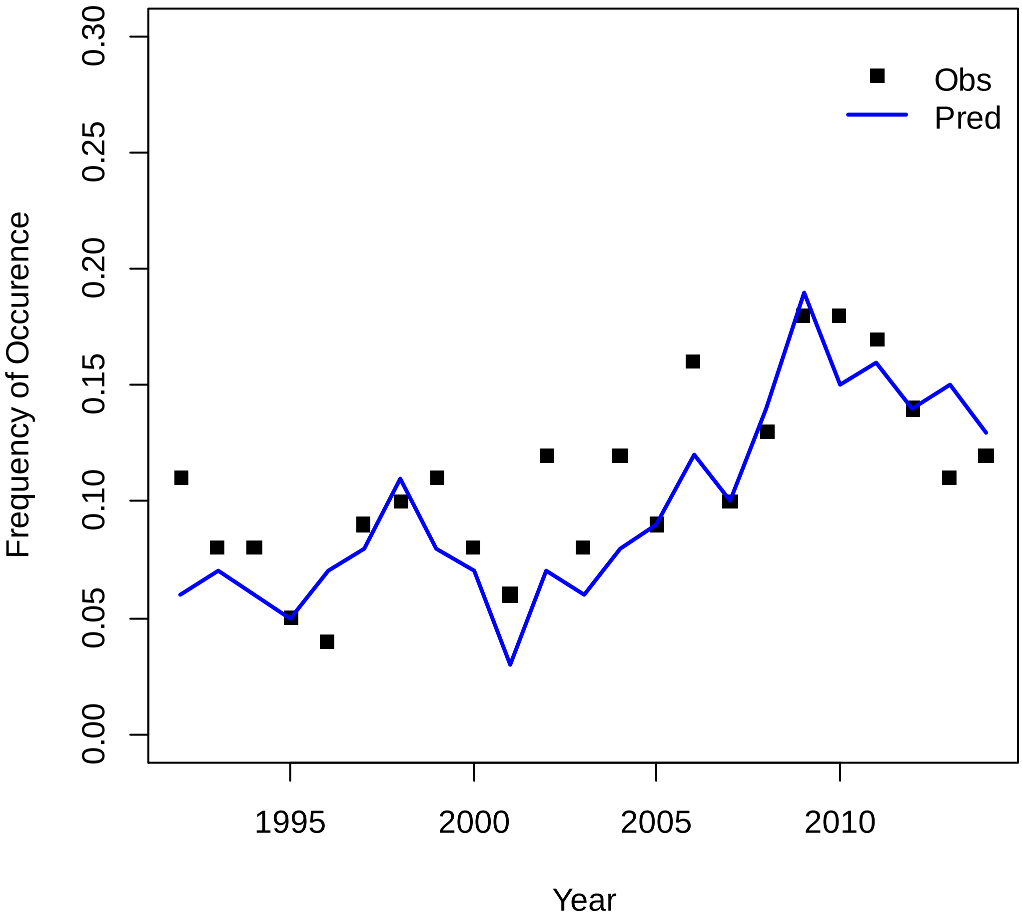

Figure 7. Observed and binomial GLM predicted frequency of occurrence of bluefin tuna on observed longline sets in the Northwest Atlantic Ocean.

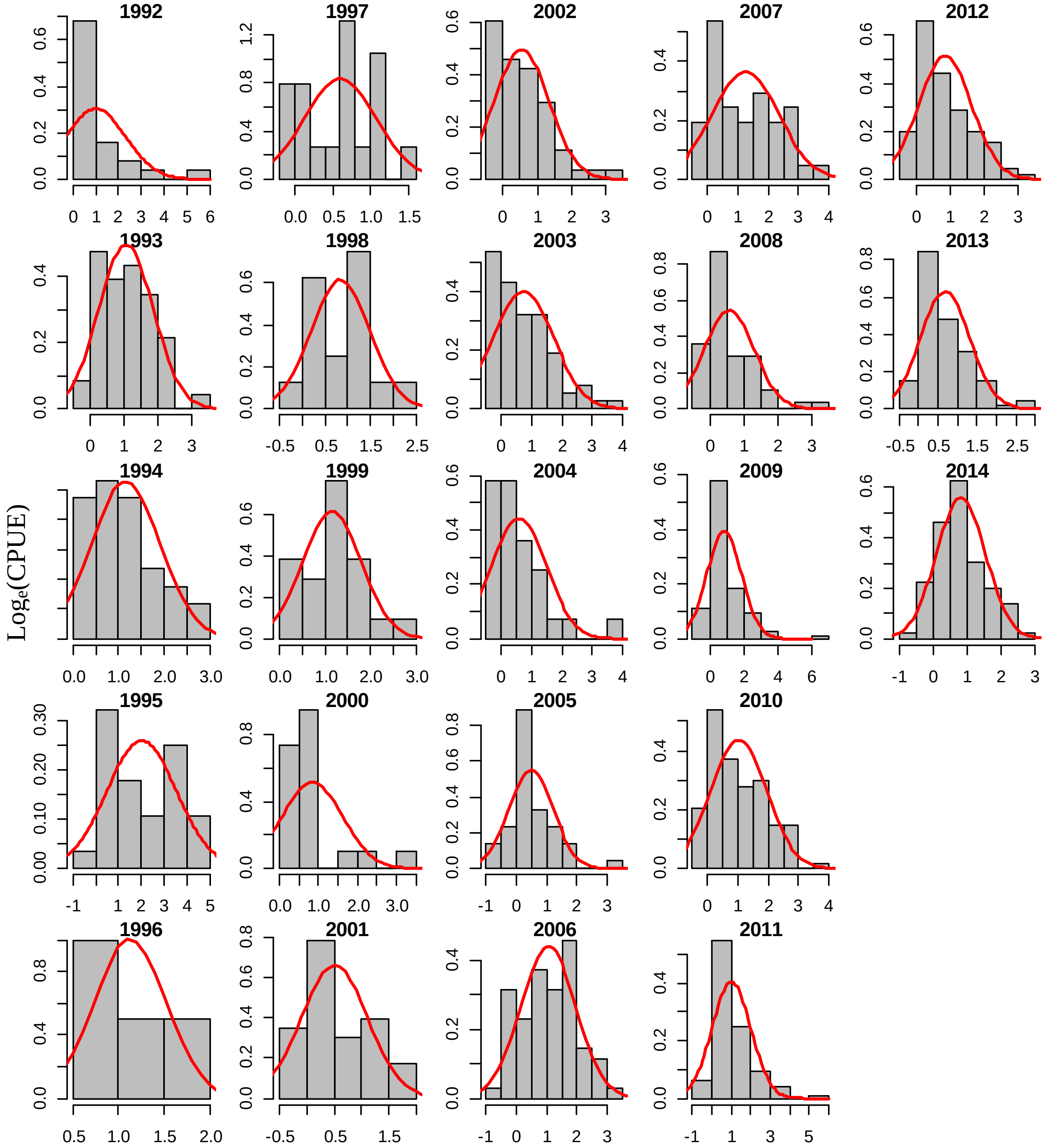

Figure 8. Normal probability model fits to the log$_e$-transformed positive CPUE data.

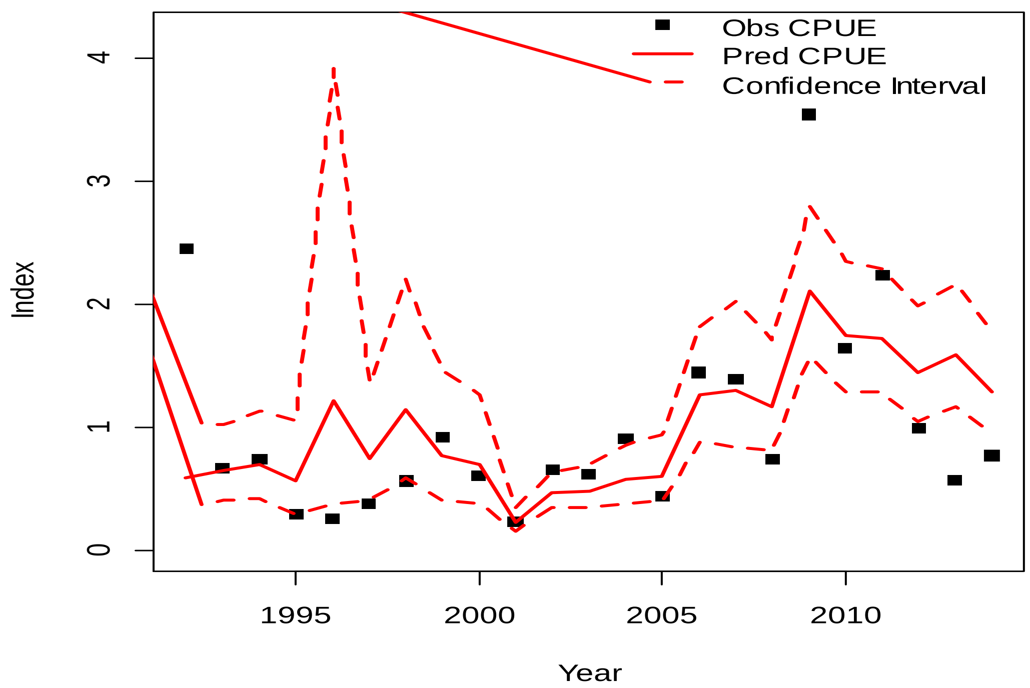

Figure 9. Delta-lognormal model standardized index of abundance of bluefin tuna in the Northwest Atlantic from the combined Canada and U.S. pelagic longline observer data.

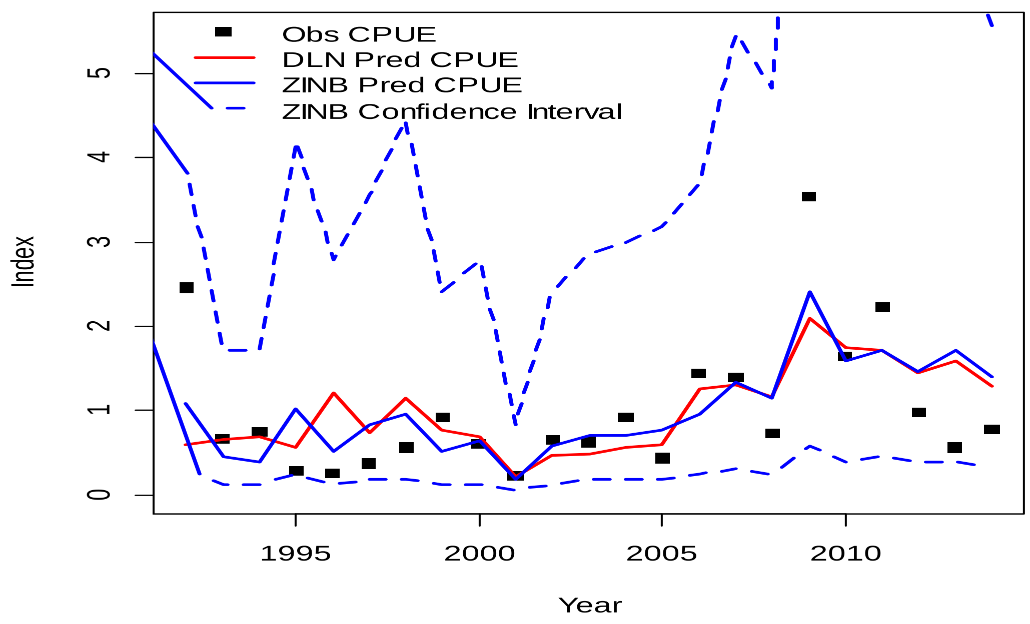

Figure 10. Comparison of the zero-inflated negative binomial (ZINB) GLM predicted index and the delta-lognormal (DLN) GLM predicted index.

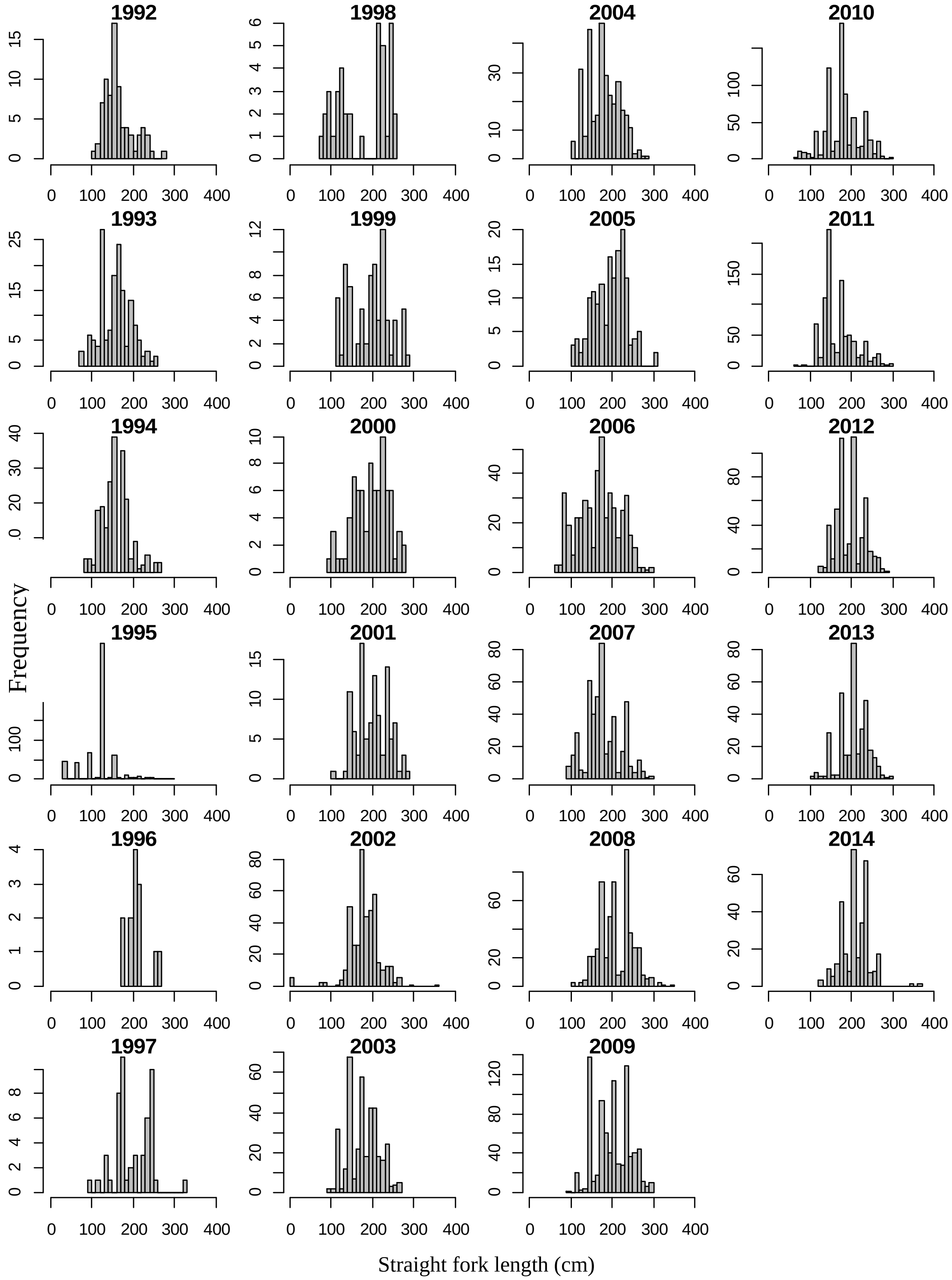

Figure 11. Observed size frequency distributions of bluefin tuna caught on pelagic longlines in the Northwest Atlantic by Canada and U.S. fleets.