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DEVELOPMENT OF FISHERY INDEPENDENT INDEX OF ABUNDANCE FOR ATLANTIC BLUEFIN TUNA IN THE GULF OF ST LAWRENCE

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SUMMARY

Fishery dependent indices of abundance are known to be problematic over the long term due to changes in the catchability resulting from industry and management initiatives. Unfortunately, the development of a fishery independent index is a costly long term (7-10 years) commitment. Here we examine a historical Atlantic herring annual acoustic survey (1993-2016) for bluefin tuna. The survey design and acoustic hardware has essentially remained unchanged since inception. Traditionally, the data were scrutinized for herring only and all other species removed before integration. This study re-examined the entire dataset for bluefin like targets. Targets were identified based target strength established from actual bluefin in situ TS measurements. Overall 862 bluefin tuna targets were identified from 14 stratum in the 22 year time series (mean=39-1). Average transect coverage was about 800 km/year. Trends in abundance (number /km) from the acoustic survey followed a similar trajectory as the CPUE index, but without the extreme inter-annual variability. Exploration of acoustic data sets from other areas may reveal similar information that could be used to develop additional fishery independent indices of abundance.

RÉSUMÉ

Il est notoire que les indices d'abondance dépendants des pêcheries posent problème à long terme en raison des changements de la capturabilité découlant de l'industrie et des initiatives de gestion. Malheureusement, la mise au point d'un indice indépendant des pêcheries est une entreprise coûteuse et réalisable à long terme (7 à 10 ans). Le présent document aborde une prospection acoustique annuelle historique concernant le hareng de l'Atlantique (1993-2016) pour le thon rouge. La conception de la prospection et le matériel acoustique sont restés en grande partie inchangés depuis leur création. Traditionnellement, les données ont été examinées uniquement pour le hareng et toutes les autres espèces ont été supprimées avant leur intégration. La présente étude réexaminait l'ensemble du jeu de données en ciblant le thon rouge. Les cibles ont été identifiées sur la base de la réponse acoustique (TS) établie à partir des mesures des valeurs de réponse acoustique du thon rouge effectuées in situ. Dans l'ensemble, 862 cibles de thon rouge ont été identifiées à partir de 14 strates dans la série temporelle de 22 ans (moyenne = 39-1). La couverture moyenne des transects s'élevait à environ 800 km/an. Les tendances de l'abondance (nombre/km) de la prospection acoustique présentaient une trajectoire similaire à celle de l'indice de CPUE, mais ne montraient pas de variabilité interannuelle extrême. L'exploration des jeux de données acoustiques d'autres zones peut révéler des informations similaires qui pourraient être utilisées pour développer d'autres indices d'abondance indépendants des pêcheries.

RESUMEN

Se sabe que los índices de abundancia dependientes de la pesquería son problemáticos a largo plazo debido a los cambios en la capturabilidad debidos a iniciativas de la industria y la ordenación. Lamentablemente, el desarrollo de un índice independiente de la pesquería supone un compromiso costoso y a largo plazo (7-10 años). Aquí se examina una prospección acústica anual histórica de arenques atlánticos (1993-2016) para el atún rojo. El diseño de prospección y el

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programa informático acústico de la prospección han permanecido básicamente invariables desde su creación. Tradicionalmente, los datos se examinaron sólo para el arenque y todas las otras especies se eliminaron antes de la integración. En este estudio se reexamina el conjunto de datos completo para el atún rojo como objetivo. La especie objetivo se identificó basándose en la respuesta acústica establecida a partir de mediciones de la TS de atún rojo in situ. En total se identificaron 862 atunes rojo objetivo a partir de 14 estratos en la serie temporal de 22 años (media = 39 - 1). El promedio de cobertura del transecto fue de unos 800 km/año Las tendencias en la abundancia (número/km) de la prospección acústica siguieron una trayectoria similar a la del índice de CPUE, pero sin la extrema variabilidad interanual. La exploración de conjuntos de datos acústicos de otras áreas podría revelar información similar que se podría utilizar para desarrollar índices de abundancia independientes de la pesquería adicionales.

KEYWORDS

Acoustics, index of abundance, bluefin tuna

Introduction

Atlantic Bluefin tuna (*Thunnus thynnus*) are assessed and managed by the International Commission for the conservations of Atlantic tunas (ICCAT). The resource is divided into two stocks: the eastern, which spawns in the Mediterranean and the western which spawns in the Gulf of Mexico (Baglin, 1982; Block *et al.*, 2005; Rooker *et al.*, 2007; Richardson *et al.*, 2016). The status of both stocks are evaluated on a regular bases using a virtual population analysis (VPA) calibrated with multiple fishery dependent indices of abundance (SCRS, 2014). Recently the SCRS has expressed concern about the assumptions associated with these fishery based catch per unit effort (CPUE) indices of abundance and the uncertainty of biomass estimates based on these inputs. This led the SCRS to the recommendation that new fishery independent indices be developed for both stocks (SCRS, 2013). A number of initiatives have been proposed by ICCAT member countries, but the assessment model inputs from any new index will not be available for several years. Currently, Canada contributes two standardized CPUE indices of abundance for Bluefin tuna based on the commercial fishery; one from catches in the Gulf of St Lawrence and the other in Southwest Nova Scotia. The Canadian fisheries have undergone changes in fishing patterns and regulations that likely violated the assumption of constant catchability over time. Both have been subjected to scrutiny in recent years given their conflicting trajectories, changes to the fishery, and influence on the model results for western bluefin.

The Gulf of St Lawrence (GSL) represents a major summer/fall feeding area for adult Atlantic bluefin tuna. The co-occurrence of Atlantic herring and Atlantic bluefin tuna is a common observation in the GSL according to local fishers. Each year large numbers of bluefin tuna are found feeding on aggregations of herring (spawning and feeding) in the shallow near shore waters. This is particularly apparent when gillnets are being retrieved on many of the herring spawning grounds (Melvin, 2016). Bluefin are observed almost nightly (herring fishing generally occurs at night) feeding on the spillage as the nets are retrieved or being feed by the vessel crew. Consequently, it was not surprising that bluefin tuna were detected in the annual herring acoustic survey assuming the fish did not actively avoid the survey vessel. Unfortunately, the surveys are interested in the spawning biomass of herring and species other than herring are either removed or ignored in the acoustic data analysis (Melvin *et al.*, 2008 LeBlanc *et al.*, 2014; Gregoire *et al.*, 2011).

The Canadian Department of Fisheries and Oceans has undertaken an annual fall acoustic survey for herring in the Gulf of St Lawrence since the early 1990's. Until now these data have only been examined for herring as the editing process removed all backscatter except that associated with the target species from the analysis. Given the known co-occurrence of Atlantic herring and Bluefin tuna a preliminary analysis of the raw (unedited) acoustic data was conducted to explore the possible documentation of Bluefin tuna during the survey. The results indicated the presence of tuna like targets in several years of the raw data files. Based on the preliminary results it was decided to undertake a major re-analysis of these data to investigate the potential development of a new, and fisheries independent, index of abundance for bluefin in the Gulf of St Lawrence. Here we provide an overview of the re-analysis for 24 years of the acoustic survey data. The results represent a new fishery independent western Bluefin tuna index of abundance, in terms of the number of BFT observed per km, developed from existing survey data covering the period 1993-2015. The index will be used in the 2017 western Bluefin tuna stock assessment (SCRS, 2017).

Material and Methods

The annual acoustic survey for Atlantic herring in the southern Gulf of St. Lawrence survey has been undertaken by the same vessel, during the same time interval, using essentially the same acoustic equipment since 1992. Although the survey began in 1991 it wasn't until 1993 the protocols were standardized. Survey coverage focused on two areas in the Southern Gulf of St Lawrence: the Gaspasie/Baie de Chaleur and the northern coast of Prince Edward Island (PEI) (**Figure 1**). The survey used a random stratified parallel transect design that remained unchanged since 1994, except the number of strata occupied in a given year varied due to weather and time constraints. In 2015 the vessel changed to a completely different style (cat vs single hull) and in 2016 the acoustic hardware to a scientific system (EK60). The number of transects per stratum depended upon the stratum area and ranged from 5 to 15 for a survey. In recent years, and in the past, only some of the strata around PEI were surveyed because of limitations of suitable ports for the survey vessel. Unfortunately, no PEI stratum have been surveyed since 2012. Even in the Gaspe Bay and Baie des Chaleur which was the focus of the survey not all stratum were surveyed annually. As such our detailed analysis focused only on 14 of the 28 stratum in the Baie des Chaleur area which have been consistently visited with one or two missed years (**Figure 2**).

The survey was conducted from 1992 to 2003 with a Simrad EY 500 (120kHz) single beam transducer deployed from the Canadian Coast Guard Geographical Services vessel the “F.H. Creed” (**Figure 1**). The acoustic transciever was replaced with an HDPS DE 9320 echo-sounder in 2003 due to equipment failure, but the transducer remained unchanged. By design the sampling unit for herring was defined as a transect where estimates of biomass, and associated error, are firstestimated for each strata then combined to obtain a total herring biomass (LeBlanc et at, 2015). The stratum vary in area (106-521km^2) and annual number of transects ranging from 78 to 147. The minimum number of transects per stratum was 3 and the maximum 16. A similar design was retained for tuna where transect was considered the sampling unit and mean number of tuna/km by transect and stratum were explored with and without area weighting. Indices of abundance were developed as the mean number of observed BFT per km (/km) of transect, by stratum and area weighted stratum.

Biological samples for herring were obtained by a separate fishing operation using government and chartered fishing vessels. No BFT samples were collect throughout the time series during the survey, however, landings in the area indicate a size distribution consistent with catches off PEI.

Data processing

All data editing and processing were undertaken using Echoview software (Version 6.1/7.1) by Myrix. The initial step in the process was to establish surface and bottom boundaries in which the software would look for individual fish targets. The bottom boundary Sea bed (i.e.,sea bed) was automatically defined using Echoview’s best bottom candidate algorithm with a 0.5 offset. Visual inspection of the bottom was also undertaken to repair any problem areas or false detections. The surface boundary was identified as 2.0 meters below the transducer, except greater when surface reverberation was strong due to rough weather areation or other interference. Once the boundaries were established fish schools (presumably herring) were identified, using Echoviews school detection algorithm, and removed from the analysis. Because it is extremely difficult to discerning large individual targets within a densely aggregated school of fish, only single targets outside the schools were considered as candidates for BFT. This greatly reduced the amount of echogram scrutinizing for BFT. Quantitative analyses of the schools were used for quality control to insure consistency in editing practices for herring. The echograms were then partitioned into transects (i.e., sampling units).

Individual targets were identified using Echoviews standard single target detection algorithm. The data were futher filtered using a TS window for BFT. The upper and lower threshold of a BFT single echo target strength (TS) was defined as -33 and -16 dB respectively based on the peer reviewed literature, in-situ acoustic observations of Atlantic Bluefin tuna, and the survey data (Melvin, 2016). All targets that fell within the target strength range were individually examined to visually confirm that they were likely BFT and the number summed for each transect. The analysis looked at two approaches to developing an index of abundance; total number observed/total distance covered in a stratum and the mean transect/ number/km. Both methods produced a mean number of observed BFT/km in each stratum by year. The latter was subjected to a stratum area weighted analysis to account for differences in the number of transects and stratum area. To be consistent with over time and to accommodate the change from single to split beam transducer, only the uncompensated TS was used to determine the target/

Results:

A total of 28 strata were surveyed in the Bae des Chaleur/Miscou area from 1992 to 2015, however due to a variety of factors (weather and mechanical problems) not all were covered annually. **Figure 2** provides an overview of the surveyed stratum. Only stratum with 2 or less missing years were included in the analysis which resulted in 14 of 28 strata being used to estimate the number of BFT/km for the index. Several strata were also excluded because, although they were occupied annually, virtually no tuna were observed through the time series. Data from 1993 were eliminated due to a number of missing stratum. The number of tuna observed in each stratum by year is summarized in **Table 1**.

Although strata around PEI were visited intermittently over the time series, this coverage has been essentially terminated having been surveyed only once in the last 6 years. The data were analyzed and the results discussed for only the 14 strata occupied on a regular basis. **Table 2** provides a summary of the transects undertaken in each stratum by year. A value of 0 indicates that no transects were conducted in that year. The number of tuna observed per year ranged 5 to72 and the distance traveled 304 to 1054km in a given stratum (**Table 3**).

The indices of abundance were estimated from the stratum mean number of BFT observed per km of survey and for the stratum area weighted mean number per km (Table 4 and Table 5). All means are based on the number of BFT observed along a transect standardized to a km The nominal CPUE index shows a gradual increase from 1996 to 2009 when the index increases sharply and remains relatively high until 2012 (**Figure 4**). Thereafter the index declines dramatically until 2015 but is well above the CPUE observed in the 1990. The stratum mean shows more inter-annual variability during the earlier years than the CPUE with a general decline until 2002. From 2002 the stratum mean increased to 2009, with inter-annual variability, peaking in 2012. The index declined in 2013 then increased in 2014 and 2015 unlike the CPUE index which showed a decline between 2013 and 2015. The area weighted stratum mean showed a similar pattern as the unweighted mean however the inter-annual variability was reduced and several peaks were diminished (**Figure 4**). This index showed a decline between 1996 and 2000 with a peak in 2012. Neither the stratum mean nor the area weighted stratum mean peaked in 2010 as did the CPUE. This adds support to the contention that the extreme increase in the CPUE index in 2010 was a function of a change in fishing patterns and that the removal of this year from the input to the assessment was justified. The numerical values for both the unweighted and weighted stratum means are provided in Table 6.

Discussion

One of the difficult challenges in the development of a new fisheries independent index of abundance is the extended time commitment (7-10 years) involved before a new index provides useful information on trends in abundance and can be used as input in an analytical assessment. Here we have identified an existing annual acoustic survey that began in 1992 which contains quantitative information on Atlantic Bluefin tuna that may be reflective of the abundance of the species in the Gulf of St Lawrence. The fact that the data are available for more than 20 years, contain BFT, and is still ongoing annually, means if accepted as an index it could immediately be used in the assessment model for western BFT, and for many years to come, to complement the existing Gulf of St Lawrence CPUE index without the standard waiting period. In this report we present the index of abundance from 1994 to 2015. Data from 1992 and 1993 were removed from the analysis. The data from 2016 are currently being analyzed.

One of the critical aspects in isolating individual targets that could be BFT within the herring echograms is setting the range of target strengths for the species and size of fish in the area. For this analysis we used three independent sources of information: peer reviewed literature, in situ observations of BFT collected in the Gulf of St Lawrence, and analysis of the target strength frequency from the survey data itself (Bertrand *et al.*, 2000; Melvin, 2016). To date, little data has been published on target strength of tuna, most information has been collected on smaller sized Yellowfin and Bigeye tunas. Bertrand *et al.* (2000) and Manik (2009) determined relationships between fork length and TS for Yellowfin and Bigeye tunas. When using the size of tuna caught in the commercial fishery (176 – 302 FL, in 2012 and expanding the established relationships past the measured values suggests a potential range in TS of -37 to -13 dB. This assumes that the TS of BFT is similar to that of other tuna with a swim baldder. Published data to support this assumption is limited, however, one study determined that the TS of a Bluefin tuna with an average size of 182 cm is between -24 and -25 dB, with a TS maximum of -20.5 dB and the authors suggest an overall TS standard deviation of 20% (Espinosa *et al.* 2011). *In-situ* measurements of BFT collected off the coast of PEI, Canada, for 22 observations of confirmed BLT indicated a range in TS of -30 dB to – 16 dB (Melvin, 2016). The TS for tunas was compared to the single target data collected during the 2013 survey data. At approximately -35 dB the frequency of single targets decreased, this node in the frequency suggests a change in the source of the echo. Using information obtained from published literature and observations of the current data set the single target analysis we settled on a threshold of a minimum -33 dB and a maximum of -16 dB Each single target meeting the above criteria was then validated manually. Once the targets were identified as BFT obtaining an index was simply a matter of estimating the mean (#/km) for each stratum and for stratum area weighted.

One of the challenges of using acoustics in a quantitative manner is estimating the relationship of the energy reflected by a single target and the total backscatter to get an estimate of biomass. In this case however we are fortunate in that we are able to actually count the number of BFT observed per defined distance interval. Consequently, we are able to develop an index directly from the observations without converting the acoustic backscatter to biomass. This eliminates many of the controversial aspects of the technology.

Comparison of the transect mean number/km and the total number/km indicated virtually the same trends, thus we selected the former to compare stratum area weight and un-weighted patterns. The two indices of abundance (estimates of #/km) also suggest similar trajectories for the western Bluefin tuna stock. Both indices indicate that the biomass decreased between 1996 and 2002. Thereafter they both increased to a peak in 2012 a decrease in 2013 and an increase in 2014. The stratum mean decreased slightly in 2015 while the area weighted stratum mean increased slightly in 2015. The main difference between the two indices is the former indicates a peak in 2009 while the latter does not. Furthermore, neither shows the strong increase in 2010 that the CPUE index suggested. There has been a lot of discussion and uncertainty associated with the 2010 CPUE data to the point that in past assessments this year was removed from input as biologically it was considered unrealistic that the stock increased by as much as the index would suggest. These new fishery independent indices of abundance would support the contention that it should be removed. The question thus arises as to which potential fishery independent index best reflect the trends in abundance of BFT in the coverage area. We recommend the use of the stratum area weighted mean #/km as it is slightly less variable than the stratum mean and would be consistent with the survey design. Giving equal weight to unbalanced stratum area could bias the results because of the survey design.

A potential issue for this survey is the area of coverage. Examination of the distribution commercial BFT catches (2007-2013) indicated that catches in the area of the survey are relatively minor compared to the catches off northern PEI (**Figure 5**). This however does not negate the data for the development of a fishery independent index of abundance. Indices that track trends in abundance of a portion of the stock are fine providing they represent a constant portion of that stock. The area of north PEI is where the majority of BFT licence holders live. Most fishers will focus their effort near their home port rather than travel to distance waters to procure their quota. Licence holder from outside are also known to visit the area when they are uncertain of catches in the outer regions. Thus it is expected that the majority of BFT landed would be reported from the north shore of PEI and that the few catches from Coastal New Brunswick and Quebec do not reflect abundance. The acoustic survey/detection represents what BFT were present not what was caught in the survey area.

Several problems were encountered in the historical data (ie. there conversion to a standard file format) that prevented extending the proposed index further back in time before 2003. In essence, there was a vessel multiplier that was not incorporated in the common standard format beginning in 2003 and extending back several. The problem was resolved and the data back to 1994 were used in this analysis.

Major sources of uncertainty for this study are primarily related to target identification and the change in vessel and acoustic equipment in 2016. We established a minimum TS threshold boundary of -33.0 dB and a maximum of -16 dB for Bluefin tuna to eliminate a large number of individual targets. However, within this TS range there are a number of fish species (adult Atlantic cod, striped bass and Atlantic salmon) that have similar echo strengths, especially in the lower half of the TS range. For this reason each individual target was further examined visually to determine if their characteristics were consistent with those of known BFT and targets very close to bottom (<1m) were removed from the analysis. Unfortunately, there is the possibility that some targets identified as BFT were misclassified; but the extent is unknown. The effect of changing vessels and acoustic technology in 2016 on fish behaviour (vessel avoidance) and quantification (single vs split beam) is unknown and only time will tell. The survey area encompasses a small portion of the Gulf of St Lawrence Bluefin tuna distribution, how representative of abundance of fish in the gulf or for that matter the western BFT stock is unknown.

References

Bertrand, A., Josse, E., and Massé, J. 2000, In situ acoustic Target Strength measurement of tuna associated with a fish aggregating. ICES Journal of Marine Science, 57: 911-918.

Baglin, R. E. Reproductive biology of western Atlantic bluefin tuna. Fish. Bull. 80, 121–134 (1982).

Block, B.A., Teo, S.L.H., Walli, A., Boustany, A., Stokesbury, M.J.W., Farwell, C.J., Weng, K.C., Dewar, H. and Williams, T.D. 2005. Electronic tagging and population structure of Atlantic bluefin tuna. Nature 434, 1121-1127

Espinosa, V., E. Soliveres, A. Cebrecos, V. Puig, S. Sainz-Pardo, F. de la Gándara. 2011. Growing monitoring in sea cages: TS measurements issues. Proceedings of the 34th Scandinavian Symposium on Physical Acoustics, Geilo 30 January–2 February, 2011.

Grégoire. F., Beaulieu, J. L., and McQuinn, I. H. 2011. The Atlantic herring (*Clupea harengus harengus* L.) stocks of the west coast of Newfoundland (NAFO Division 4R) in 2011. Canadian Science Advisory Secretariat. Research Document 2012/121. 70p.

DFO. 2012. Assessment of the West Coast of Newfoundland (Division 4R) Herring Stocks in 2011. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/024.

LeBlanc, C.H., Mallet, A., Surette, T., and Swain, D. 2015. Assessment of the NAFO Division 4T southern Gulf of St. Lawrence Atlantic herring (*Clupea harengus*) stocks in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/025. vi + 142 p.

Melvin, G.D. 2016. Observations of in situ Atlantic bluefin tuna (*Thunnus thynnus*) with 500-kHz multibeam sonar. ICES Journal of Marine Science. doi:10.1093/icesjms/fsw077.12p.

Melvin, G.D. and N.A. Cochrane. 2014. Multibeam acoustic detection of fish and water column targets at high flow sites. Estuaries and Coasts Vol 38 Supplement 1: 227-240. DOI: 10.1007/s12237-014-9828-z: 14p.

Manik, H. M. 2009. Measurement of Acoustic Reflection of Tuna Fish Using Echosounder Instrument. ILMU KELAUTAN. Juni 2009. vol. 14 (2): 84-88.

Power, M. J., and Melvin, G. D. 2007. Summary of the 2007 Herring Acoustic Surveys in NAFO Divisions 4VWX. Canadian Science Advisory Secretariat. Research Document 2008/062. 61p.

Richardson, D.E., E., KE., Maranchik, J.R. Guyonc, M.E. Lutcavage, B. Galuardie, C.H. Lam. 2016. Discovery of a spawning ground reveals diverse migration strategies in Atlantic bluefin tuna (Thunnus thynnus). Proc Natl Acad Sci U S vol. 113 no. 12. 3299–3304

Rooker, J.R., J.R. Alvarado Bremer, B.A. Block, H. Dewar, G. De Metrio, A. Corriero, R.T. Kraus, E.D. Prince, E. Rodriguez-Marin, and D.H. Secor. Life History and Stock Structure of Atlantic Bluefin Tuna (*Thunnus thynnus*). Reviews in Fisheries Science, 15:265–310, 2007.

SCRS, 2017. *In* Report of the 2017 ICCAT Bluefin Data Preparatory meeting. Madrid, Spain 6-11 March, 2017. In ICCAT Report for Biennial Period, 2016-17. Part I (2016) – Vol. 2.

SCRS, 2013. *In* ICCAT Report for Biennial Period, 2012-13. Part I (2012) – Vol. 2.

SCRS, 2014. *In* ICCAT Report for Biennial Report, 2012-13. Part II (2013) – Vol. 2.

Table 1. Summary of the number of bluefin tuna observed in each stratum from 1993-2015. Stratum highlighted in gray were not used in the development of an index of abundance.

Stratum\Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
American_Bank				1	1						5	0	1											8
Beaufils	1	0		1	0	0	0	0	1	0	0	0	0	0	2	1		0	1	0	1			7
Belledune	0	0	0	4	0	1	1	1	7	0	0	5	3	10	15	2	0	9	7	11	6	6	14	102
Cap_Bon_Ami	3			1	0	0	0		0	0	0	0	0	0		0			0	0	0	1		2
Cen_Chal		0																						0
Est_Cen_Chal	0	0																						0
Gaspe_Bay	0	0									0				0									0
Gaspe_Off		0		0	0	0	0	0	0	0	0	0	1	0		1								2
Grand_Riv	0	2	4	1	4	3	3	0	1	0	2	0	0	0	2	7	6	7	7	5	3	1	8	66
Maisonette	0	0	0	0	2	1	0	0	0	0	0	1	7	0	0	3	9	8	3	14	11	8	5	72
Malbaie	0	0		0	0	0	0		0	0	0	0	0	0	1	0		0	4	1	0	0		6
Miscou_NE		0	2	0	2	0	0	0	0	0	0	0	3	2	5	5	0	3	2	1	2	7	8	42
Miscou_NW	4	0	0	0	2	1	0	0	0	0	0	1	7	0	0	3	9	8	3	14	11	8	5	72
Miscou_SE		0	3	3	4	4	2	1	5	0	1	4	5	0	1	3	3	3	1	0	4	6	4	57
Miscou_SW	0	0	1	0	0	0	4	0	0	0	0	6	9	7	1	1	4	7	1	3	2	3	0	49
Nepisguit		8	1	0	0	1	1	0	1	1	10	5	5	11	10	3	3	4	12	5	11	4	4	100
New_Carl		4	0	3	0	1	1	1	0	1	0	3	0	3	2	1	1	2	3	5	3	4	7	45
New_Carl_Off		6																						6
New_Rich		0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	3	5	6	0	3	6	0	27
New_Rich_Off		5																						5
Newport	0	0	0	3	0	1	1	0	0	0	1	0	3	2	2	0	8	2	2	0	0	5	1	31
North_Miscou		0	0	6	6	1	0	1	0	1	4	2	5	3	5	5	4	7	2	15	2	5	2	76
Pte_Seche	1			0	1	0	0		0		0	1	0	1	0	0								3
Riv_Rerd				0	2	0	0		0	0	1	0	0	0	2	1			4	0	1	1		12
Shigawake	0	3	1	5	0	2	1	1	2	0	0	4	2	2	2	0	7	3	9	1	3	7	3	58
Tracadie_E			0	3	2		0	3																8
Tracadie_W			0	8	3			0	3															14
West_Miscou	8	3	0	7	3	0	0	0	3	1	25	2	7	8	2	6	8	11	5	11	7	8	2	119

Table 2. Summary of the number of transects undertaken annually in each of the 14 stratum regularly occupied throughout the time series by year.

	Year																					
Stratum	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	8	6	6	6	10	10	9	10	6	10	14	14	11	13	17	0	15	16	16	16	16	15
2	8	8	9	7	8	9	6	6	5	9	9	10	8	8	8	5	8	8	8	7	8	4
3	12	13	13	13	15	10	15	15	10	12	14	14	12	11	14	13	12	11	10	10	10	9
4	6	5	5	5	5	4	5	4	4	0	6	6	5	5	4	7	6	7	8	7	8	4
5	7	8	7	8	8	4	7	7	6	11	9	10	10	8	8	10	10	7	10	9	10	4
6	4	3	5	5	3	5	5	4	0	6	5	6	0	5	7	6	4	4	0	5	4	3
7	5	7	7	7	4	5	5	5	0	0	5	6	8	5	8	7	5	4	2	5	5	3
8	8	9	10	8	13	8	14	16	9	14	13	14	12	12	15	6	13	16	13	12	14	12
9	11	9	9	8	6	7	5	5	5	0	8	8	7	7	9	10	10	10	11	13	10	13
10	13	6	6	5	6	6	4	4	3	0	4	6	6	5	5	6	8	7	7	7	5	5
11	10	9	9	6	6	8	5	7	7	8	7	9	8	9	7	8	9	10	9	10	10	4
12	1	0	4	7	11	5	8	8	4	12	12	11	7	10	10	12	10	9	8	8	7	6
13	14	17	17	16	16	14	12	15	13	21	19	19	12	14	16	15	16	15	14	19	15	9
14	11	0	11	9	9	8	8	9	6	16	12	14	10	12	14	15	13	11	10	10	11	9
Total	118	100	118	110	120	103	108	115	78	119	137	147	116	124	142	120	139	135	126	138	133	100

Table 3. Number of Bluefin tuna observed annually in each of the 14 regularly occupied stratum.

	Year																						
Stratum	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
1	0	0	4	0	1	1	1	7	0	0	5	3	10	15	2	0	9	7	11	6	6	14	102
2	0	0	1	0	2	2	0	0	0	0	0	0	2	0	1	4	0	6	1	1	0	3	23
3	3	2	4	1	4	3	3	0	1	0	2	0	0	0	2	7	6	7	7	5	3	1	61
4	0	2	0	2	0	0	0	0	0	0	0	3	2	5	5	0	3	2	1	2	7	8	42
5	0	0	0	2	1	0	0	0	0	0	1	7	0	0	3	9	8	3	14	11	8	5	72
6	0	3	3	4	4	2	1	5	0	1	4	5	0	1	3	3	3	1	0	4	6	4	57
7	0	1	0	0	0	4	0	0	0	0	6	9	7	1	1	4	7	1	3	2	3	0	49
8	8	1	0	0	1	1	0	1	1	10	5	5	11	10	3	3	4	12	5	11	4	4	100
9	4	0	3	0	1	1	1	0	1	0	3	0	3	2	1	1	2	3	5	3	4	7	45
10	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	3	5	6	0	3	6	0	27
11	0	0	3	0	1	1	0	0	0	1	0	3	2	2	0	8	2	2	0	0	5	1	31
12	0	0	6	6	1	0	1	0	1	4	2	5	3	5	5	4	7	2	15	2	5	2	76
13	3	1	5	0	2	1	1	2	0	0	4	2	2	2	0	7	3	9	1	3	7	3	58
14	3	0	7	3	0	0	0	3	1	25	2	7	8	2	6	8	11	5	11	7	8	2	119
Total	21	10	36	18	18	16	9	18	5	41	35	50	50	45	33	61	70	66	74	60	72	54	862

Table 4. The area surveyed annually for each of the 14 stratum used in the analysis. The blank "yellow highlighted" indicates the stratum was not surveyed in that year.

	Year																					
Stratum	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	348	348	348	348	348	348	348	348	348	348	348	348	299	266	266		266	266	266	266	266	348
2	174	174	174	174	87	87	87	87	87	87	87	87	106	106	106	106	106	106	106	106	106	173.8
3	138	138	138	138	138	138	138	138	138	138	138	138	145	145	145	145	145	145	145	145	145	137.8
4	524	524	524	524	266	335	297	297	297		297	297	300	353	353	353	353	353	353	353	353	353
5	524	524	524	524	524	428	415	415	415	415	415	415	385	449	444	435	444	444	444	444	444	444
6	524	524	524	524	262	493	487	487		487	487	487		521	521	521	521	521		521	521	521
7	524	524	524	524	524	524	524	524			524	524	612	552	552	552	552	552	552	552	552	552
8	278	278	278	278	278	278	278	278	278	278	278	278	268	211	211	100	211	211	211	211	211	211
9	167	167	167	167	167	167	167	167	167		167	167	169	169	169	169	169	169	169	169	169	169
10	254	254	254	254	254	254	254	254	254		254	254	112	112	112	112	112	112	112	112	112	112
11	187	187	187	187	187	128	128	128	128	128	128	128	125	125	125	125	125	125	125	125	125	125
12	418		418	418	418	418	418	418	418	417	417	415	306	296	296	296	296	296	296	296	296	296
13	323	323	323	323	323	278	278	278	278	278	278	278	266	266	266	266	266	266	266	266	266	266
14	354		354	354	354	354	354	354	354	354	354	354	358	331	331	331	331	331	331	331	331	331
Total Area	4736	3964	4736	4736	4129	4229	4172	4172	3161	2929	4171	4169	3451	3901	3896	3510	3896	3896	3375	3896	3896	4039

Table 5. Stratum area weighting by year. A value of "0" indicates that the stratum was not surveyed in a given year.

	Year																					
Stratum	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	0.073	0.088	0.073	0.073	0.084	0.082	0.083	0.083	0.110	0.119	0.083	0.083	0.087	0.068	0.068	0.000	0.068	0.068	0.079	0.068	0.068	0.086
2	0.037	0.044	0.037	0.037	0.021	0.021	0.021	0.021	0.027	0.030	0.021	0.021	0.031	0.027	0.027	0.030	0.027	0.027	0.032	0.027	0.027	0.043
3	0.029	0.035	0.029	0.029	0.033	0.033	0.033	0.033	0.044	0.047	0.033	0.033	0.042	0.037	0.037	0.041	0.037	0.037	0.043	0.037	0.037	0.034
4	0.111	0.132	0.111	0.111	0.064	0.079	0.071	0.071	0.094	0.000	0.071	0.071	0.087	0.090	0.091	0.101	0.091	0.091	0.105	0.091	0.091	0.087
5	0.111	0.132	0.111	0.111	0.127	0.101	0.099	0.099	0.131	0.142	0.100	0.100	0.112	0.115	0.114	0.124	0.114	0.114	0.132	0.114	0.114	0.110
6	0.111	0.132	0.111	0.111	0.063	0.117	0.117	0.117	0.000	0.166	0.117	0.117	0.000	0.134	0.134	0.149	0.134	0.134	0.000	0.134	0.134	0.129
7	0.111	0.132	0.111	0.111	0.127	0.124	0.126	0.126	0.000	0.000	0.126	0.126	0.177	0.142	0.142	0.157	0.142	0.142	0.164	0.142	0.142	0.137
8	0.059	0.070	0.059	0.059	0.067	0.066	0.067	0.067	0.088	0.095	0.067	0.067	0.078	0.054	0.054	0.029	0.054	0.054	0.063	0.054	0.054	0.052
9	0.035	0.042	0.035	0.035	0.040	0.039	0.040	0.040	0.053	0.000	0.040	0.040	0.049	0.043	0.043	0.048	0.043	0.043	0.050	0.043	0.043	0.042
10	0.054	0.064	0.054	0.054	0.061	0.060	0.061	0.061	0.080	0.000	0.061	0.061	0.032	0.029	0.029	0.032	0.029	0.029	0.033	0.029	0.029	0.028
11	0.039	0.047	0.039	0.039	0.045	0.030	0.031	0.031	0.040	0.044	0.031	0.031	0.036	0.032	0.032	0.036	0.032	0.032	0.037	0.032	0.032	0.031
12	0.088	0.000	0.088	0.088	0.101	0.099	0.100	0.100	0.132	0.142	0.100	0.100	0.089	0.076	0.076	0.084	0.076	0.076	0.088	0.076	0.076	0.073
13	0.068	0.082	0.068	0.068	0.078	0.066	0.067	0.067	0.088	0.095	0.067	0.067	0.077	0.068	0.068	0.076	0.068	0.068	0.079	0.068	0.068	0.066
14	0.075	0.000	0.075	0.075	0.086	0.084	0.085	0.085	0.112	0.121	0.085	0.085	0.104	0.085	0.085	0.094	0.085	0.085	0.098	0.085	0.085	0.082

Table 6. Summary statistics for the proposed fishery independent index of abundance using the stratum mean number of BFT per kilometer and the stratum area weighted mean number of BFT per kilometer.

	Stratum	Number	Stratum mean #/km			Stratum Area weighted mean #/km		
Year	Surveyed	Transects	Mean # /km	2*Standard Error	CV	Mean # /km	2*Standard Error	CV
1994	14	118	0.039	0.0013	0.183	0.026	0.0134	0.275
1995	12	100	0.025	0.0009	0.179	0.034	0.0085	0.135
1996	14	118	0.067	0.0012	0.098	0.067	0.0123	0.098
1997	14	110	0.029	0.0009	0.156	0.038	0.0084	0.119
1998	14	120	0.056	0.0016	0.159	0.042	0.0169	0.213
1999	14	103	0.038	0.0008	0.110	0.035	0.0078	0.120
2000	14	108	0.022	0.0005	0.121	0.019	0.0050	0.138
2001	14	115	0.026	0.0010	0.207	0.037	0.0100	0.145
2002	12	78	0.020	0.0008	0.185	0.020	0.0067	0.186
2003	10	119	0.036	0.0009	0.143	0.036	0.0098	0.144
2004	14	137	0.035	0.0005	0.078	0.038	0.0051	0.071
2005	14	147	0.041	0.0004	0.066	0.051	0.0052	0.054
2006	13	116	0.055	0.0008	0.083	0.062	0.0086	0.073
2007	14	124	0.045	0.0010	0.122	0.042	0.0103	0.131
2008	14	142	0.032	0.0004	0.079	0.034	0.0049	0.076
2009	13	120	0.074	0.0009	0.069	0.057	0.0096	0.090
2010	14	139	0.059	0.0005	0.046	0.065	0.0051	0.042
2011	14	135	0.072	0.0007	0.055	0.050	0.0075	0.080
2012	13	126	0.086	0.0012	0.077	0.101	0.0126	0.065
2013	14	138	0.056	0.0005	0.057	0.056	0.0060	0.057
2014	14	133	0.079	0.0008	0.061	0.076	0.0090	0.063
2015	14	100	0.075	0.0125	0.099	0.075	0.0138	0.098

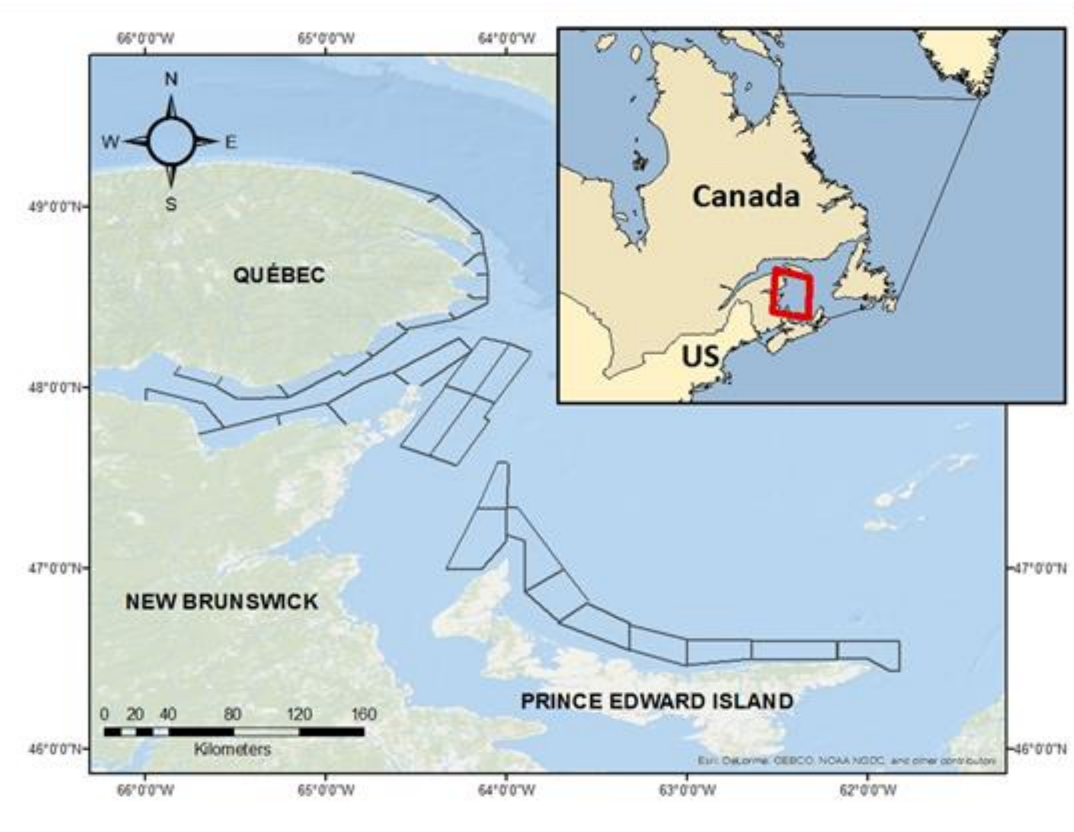

Figure 1. Map of 1992-2014 herring acoustic survey and the distribution of stratum along the coast of New Brunswick, Quebec, and PEI. Stratum around PEI were not visited on an annual bases and even when visited were often incomplete. See **Table 1** for a summary.

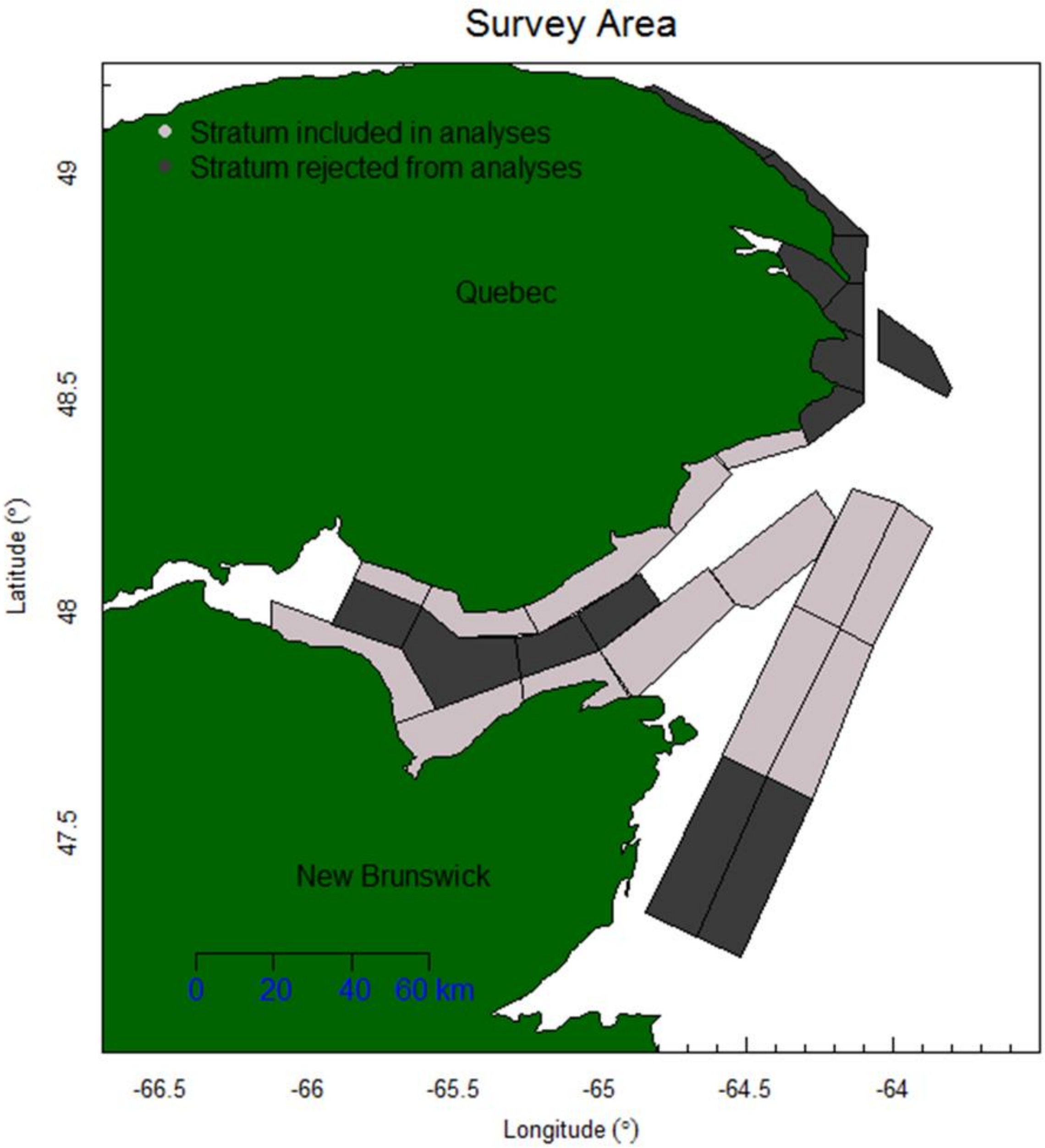

Figure 2. Summary of the Baie des Chaleur strata used in the analysis. The dark grey strata contained insufficient or incomplete coverage to be used in the time series.

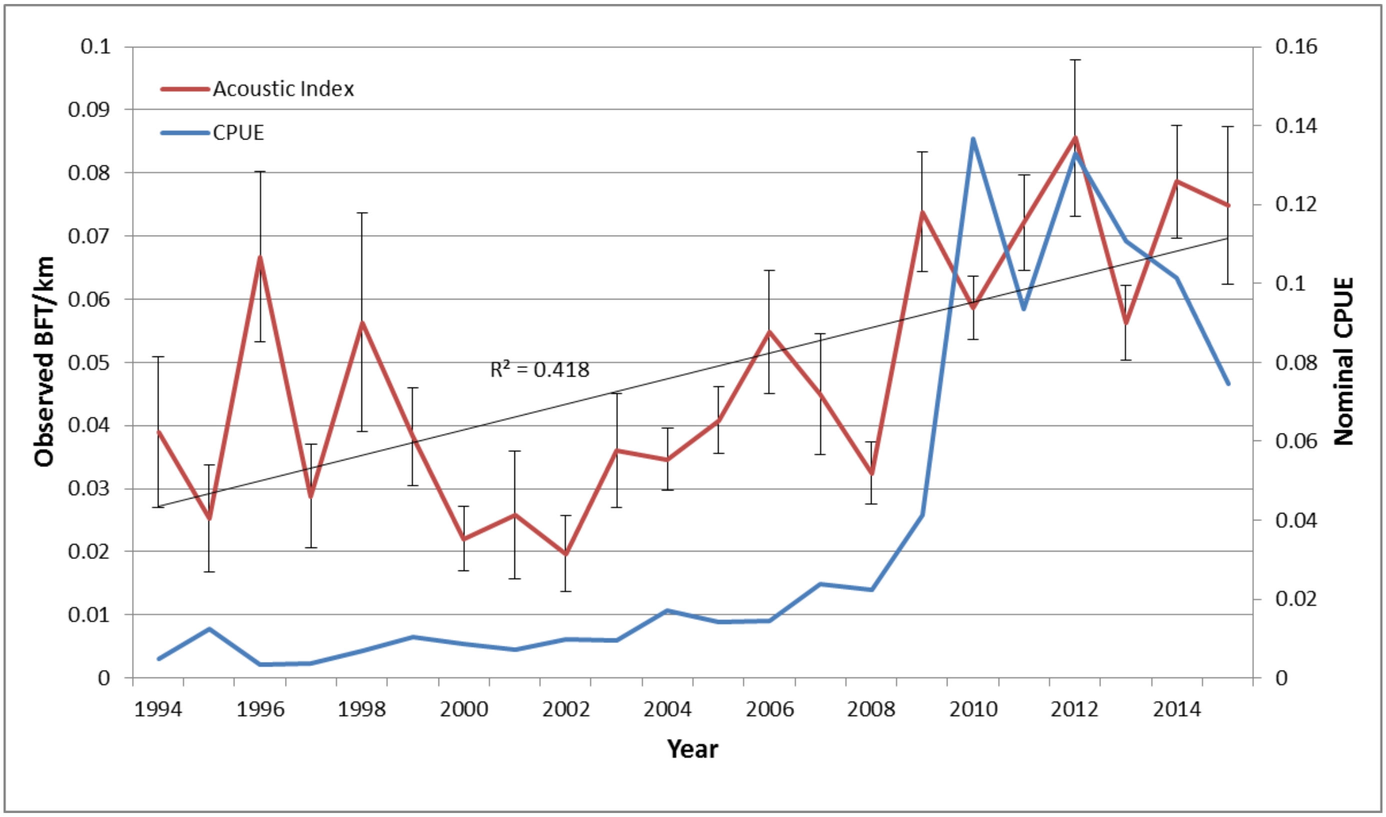

Figure 3. The stratum mean number of observed BFT/kilometer (#/km) with error bars (2* standard error) vs the nominal CPUE index currently used for the Gulf of St Lawrence from 1994 to 2015.

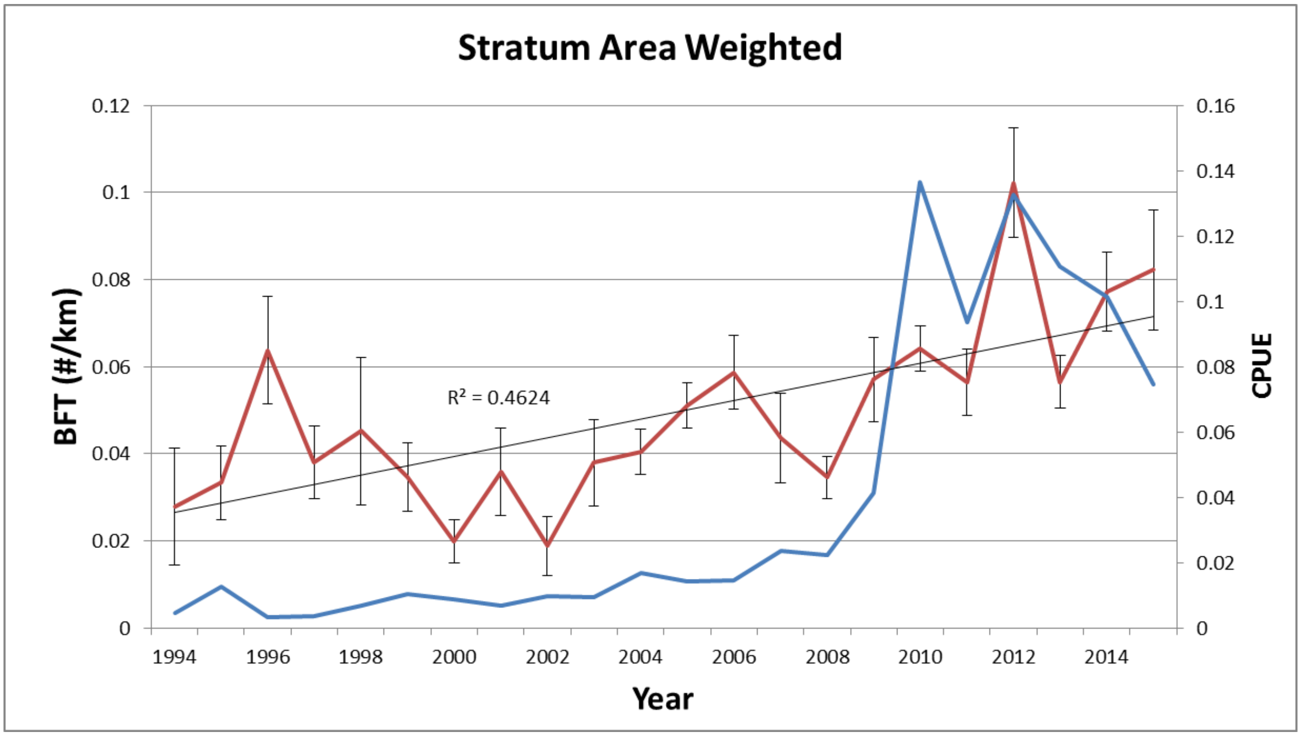

Figure 4. The stratum area weighted mean number of observed BFT/kilometer (#/km) with error bars (2* standard error) vs the nominal CPUE index currently used for the Gulf of St Lawrence from 1994 to 2015.

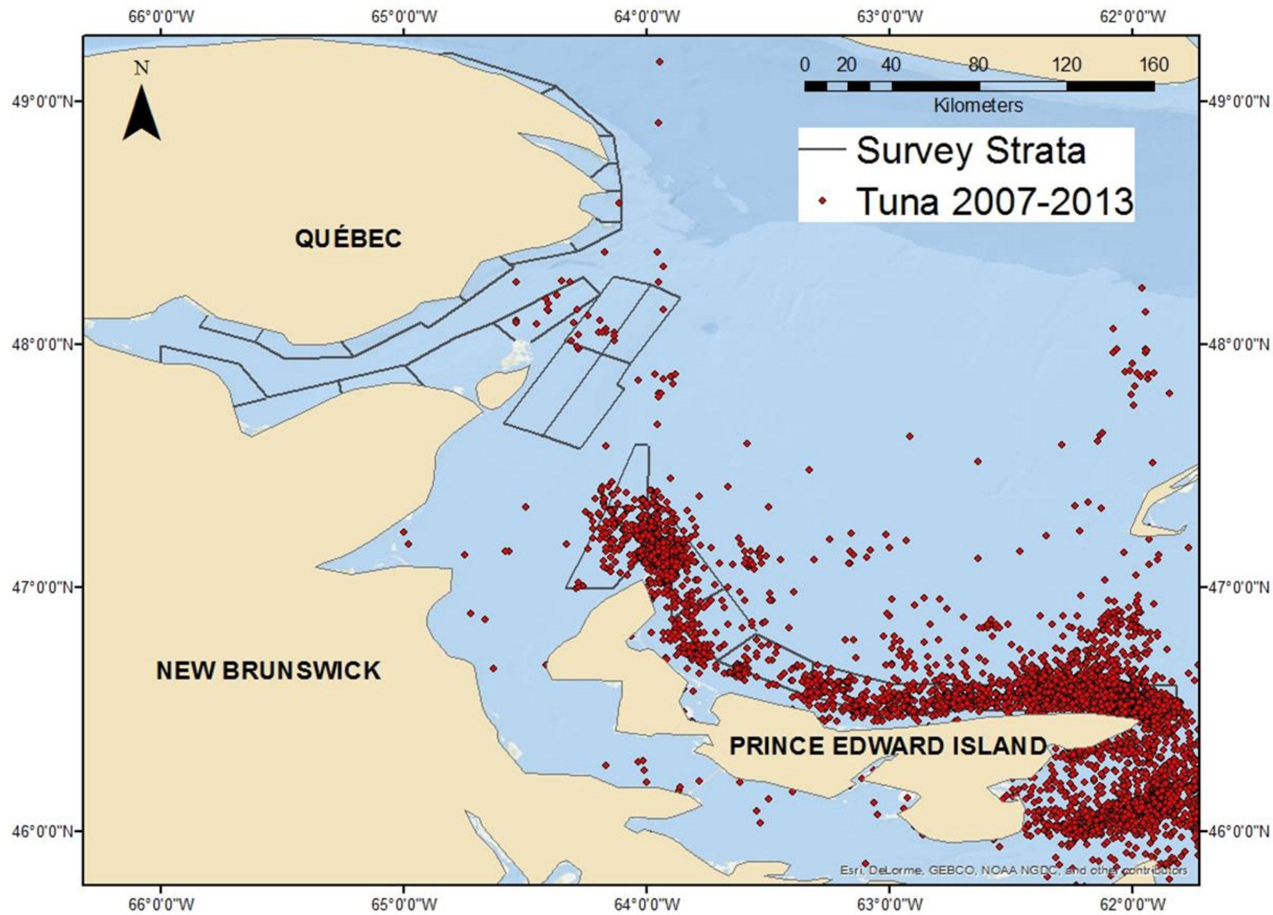

Figure 5. The distribution of commercial Bluefin tuna catches in the herring acoustic area from 2007-2013.