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REVIEW OF GULF OF ST. LAWRENCE BLUEFIN TUNA ACOUSTIC INDEX OF ABUNDANCE

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SUMMARY

Prior to 2018, the Gulf of St. Lawrence BFT acoustic index has been relatively consistent in trend with the GSL CPUE index, however, recent updates (2018-2019) suggest a significant decline in BFT that does not appear to be consistent with CPUE. Here we investigate the effects of survey methodology, spatial distribution of Atlantic Bluefin tuna, prey species abundance and environmental co-variates as factors that may be contributing to the lower index values. Results suggest that the recent index values do not appear to be related to survey methodology and certain environmental covariates (thermocline depth and cold intermediate layer). Tagging data for Bluefin in the survey area suggests that BFT may be entering the Baie-des-Chaleurs in months prior to the survey. Factors such as a decline in primary prey species (herring and mackerel) and anomalies in environmental covariates (sea-surface temperature and timing of cooling to 10°C) may be playing a role. We present options for future use of the index in assessment and MSE.

RÉSUMÉ

Avant 2018, la tendance de l'indice acoustique du thon rouge du golfe du Saint-Laurent était relativement cohérente avec l'indice de CPUE du GSL ; cependant, les mises à jour récentes (2018-2019) suggèrent un déclin significatif du thon rouge qui ne semble pas être cohérent avec la CPUE. Ici, nous étudions les effets de la méthodologie de la prospection, de la distribution spatiale du thon rouge de l'Atlantique, de l'abondance des espèces proies et des covariables environnementales comme facteurs pouvant contribuer aux valeurs inférieures de l'indice. Les résultats suggèrent que les récentes valeurs de l'indice ne semblent pas être liées à la méthodologie de la prospection ni à certaines covariables environnementales (profondeur de la thermocline et couche intermédiaire froide). Les données de marquage du thon rouge dans la zone de la prospection suggèrent que le thon rouge pourrait entrer dans la Baie-des-Chaleurs dans les mois précédant la prospection. Des facteurs tels qu'un déclin des principales espèces proies (hareng et maquereau) et des anomalies dans les covariables environnementales (température de la surface de la mer et moment du refroidissement à 10°C) pourraient jouer un rôle. Nous présentons des options pour l'utilisation future de l'indice dans l'évaluation et la MSE.

RESUMEN

Antes de 2018, la tendencia del índice acústico del BFT del golfo de San Lorenzo era relativamente coherente con la tendencia del índice de CPUE del GSL, sin embargo, las actualizaciones recientes (2018-2019) sugieren una disminución significativa del atún rojo que no parece ser coherente con la CPUE. Se investigaron los efectos de la metodología de la prospección, de la distribución espacial del atún rojo, de la abundancia de especies de presa y de las covariables medioambientales como factores que pueden estar contribuyendo a los valores más bajos del índice. Los resultados sugieren que los recientes valores bajos del índice no parecen estar relacionados con la metodología de la prospección ni con algunas covariables medioambientales (profundidad de la termoclina y capa intermedia fría). Los datos de marcado de BFT en la zona de la prospección sugieren que el atún rojo puede estar entrando en la Baie-des-Chaleurs en los meses anteriores a la prospección. Factores como la disminución de las especies de presas primarias (arenque y caballa) y las anomalías en las covariables medioambientales (temperatura de la superficie del mar y momento de enfriamiento a 10º) podrían estar desempeñando un papel. Presentamos opciones para el uso futuro del índice en la evaluación y la MSE.

KEYWORDS

Bluefin tuna, fisheries independent abundance index, acoustic

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Introduction

The acoustic index of abundance for Atlantic Bluefin tuna (ABFT) was developed in 2016 as a result of requests from ICCAT (International Commission for the Conservation of Atlantic Tunas) for more fishery-independent indices of abundance for ABFT given changes in catchability in fishery-dependent data sources. The Gulf of St. Lawrence (GSL) was identified as a region of interest for the development of fishery-independent indices as ABFT commonly use the GSL to feed on forage fish, such as Atlantic herring and mackerel.

The Atlantic herring stocks in the GSL are monitored using trawl and acoustic surveys. One such acoustic survey is conducted in the Baie-des-Chaleurs to annually monitor the biomass of fall spawners. Given the strong predator-prey association between tuna and herring, tuna were previously identified in the herring acoustic surveys (Melvin et al. 2017). The Baie-des-Chaleurs herring surveys were reviewed for tuna and resulted in the identification of individuals likely feeding on schools of herring within the Baie-des-Chaleurs strata (**Figure 1**). Similarities between the acoustic index and catch-per-unit-effort (CPUE) generated confidence that the trend in the Baie-des-Chaleurs reflected the trend in abundance for the broader GSL and was thus developed as a fishery-independent index of abundance (**Figure 2**). This index was accepted by the ABFT Species Group and the time series was used as an abundance indicator in the stock assessment in 2017. While the acoustic index has been consistent with CPUE for the majority of the time series, in more recent years (2018, 2019), the acoustic index has drastically declined and deviated from the trend in CPUE for the GSL. In addition, herring biomass has reached record lows for the same low tuna abundance years (**Figure 3**). The index was used again in the 2020 stock assessment, however, the 2018 index value was omitted.

While the initial decline in the index prompted a model-based standardization in 2019 (Gillespie *et al*., 2019), ICCAT identified the need to review additional aspects of the acoustic index in preparation for the Western Bluefin tuna assessment and MSE. In this review, we were tasked with examining variables that may help explain recent index declines. Specifically, these tasks include reviewing the survey methodology (vessel type effect/electrolysis), assessing the spatio-temporal coverage of the acoustic survey, identifying environmental covariates, characterizing the spatial distribution of ABFT and herring fishery catches (survey/tagging data), and suggesting data treatments to standardize the index. This report aims to evaluate a number of hypothesis to provide suggestions on proceeding with the acoustic index of abundance in future stock assessments. For more information on the most recent update to the acoustic index of abundance and how it is developed please refer to (Minch *et al*., 2020 and Melvin *et al*., 2017).

1. Analysis

1.1 Survey methodology

Hypothesis: Changes in survey vessel may cause vessel avoidance behavior by ABFT and thus impact the index of abundance in affected years.

The herring survey has taken place since the early 1990's using the same vessel and survey design for nearly the entire time series (1994-2014). The primary survey vessel is a catamaran style named the CCGS Frederick D. Creed. After 2014, the Creed had ongoing mechanical problems and was officially decommissioned in 2020. In years when the Creed was not operational, fishing-style vessels the CCGS Leim and CCGS M. Perley (sister vessels) were used. Although the time series was maintained by using alternative vessels, there was concern that the vessel style might impact the acoustic index by creating additional noise and deter tuna from feeding on herring when the vessel is present. This would ultimately reduce the number of tuna detected in the survey and thus impact the acoustic index. Here, we investigate if vessel changes have impacted the index in recent years.

The impact of vessel change was investigated by comparing data from recent index years (2013-2019). Since many index years have been stable and consistent with CPUE in comparison to recent years (2018-2019) the data was divided into low and high index years by assigning high and low years as "above" or "below" the median index value (0.056) of data from recent years (2013-2019). we compared acoustic data for consecutive survey years (2014 Creed versus 2015 Leim) when Bluefin tuna counts were observed to be high and made the same comparison during low index years (2018 Creed versus 2018 Perley). Detections of tuna and herring were compared across categories (High:Creed versus High:Leim and Low:Creed versus Low:Perley) by transect and depth categories (0-100 meters). To verify the effect of vessel, a negative binomial model was created using all data from the time series (1994-2019) to determine if vessel and stratum categories were able to explain the number of tuna identified per transect.

Overall, there appears to be considerable overlap between categories and the use of the Perley or Leim does not appear to impact the number of tuna identified per transect (**Figure 4**), however, the negative binomial model suggest that the acoustic index was higher in transects completed by the Leim in 2015 (p=0.044).

Despite the significant result, the Leim was used in a high index year before the acoustic index declined and thus has no impact on the current state of the index. This suggests that changes in vessels have not impacted the recent changes in the index. These results are in agreement with a review of vessel avoidance behavior of fish relative to supposedly noisy and quiet vessels. The review suggests that both quiet and noisy vessels can cause vessel avoidance, since other stimuli can be responsible for avoidance such as visual cues and the ship bow wave (De Robertis and Handegard, 2013). Thus, there may be some level of vessel avoidance regardless of vessel design and may not be significantly higher in supposed noisy vessels.

Hypothesis: Electrolysis caused by ungrounded acoustic hardware may cause vessel avoidance behavior from ABFT and thus impact the index value.

Anecdotes from fishermen were brought to our attention and suggested that electrolysis through water may occur when electronics on vessels have not been grounded (Richard Jones, pers. comm.). This concern indicated the acoustic hardware on the alternative vessels may not have been properly grounded prior to undertaking acoustic surveys, which may cause electrolysis through the water deterring tuna from the survey vessel. After discussions with the crew of the Perley we learned that the Perley is a metal fishing vessel in comparison to many commercial fishing vessels, which are mainly constructed from fiberglass. Since the Perley is composed of metal, the electronics are grounded; however, when installing electronics on fiberglass vessels the electronics need to be properly grounded. We find it exceedingly unlikely that the decline in the index was caused by electrolysis and improper grounding of electronics.

1.2 Spatial distribution of Bluefin tuna in the Gulf of St. Lawrence

Hypothesis: Mismatch survey timing and presence of tuna.

The Gulf of St. Lawrence is a feeding zone for ABFT in the summer and fall. The herring survey has taken place between September-October for the time series (1994-2019), a period that overlaps with ABFT feeding in the GSL. While the acoustic index has been consistent with CPUE for the most part, changes in the index value (2018-2019), may indicate that there has been a shift in ABFT feeding time or feeding location during that time period.

To gain a better understanding of ABFT movement within the GSL and Baie-des-Chaleurs, we used receiver detections from acoustically tagged tuna in the GSL and the US. There are a number of receivers in the GSL, some of which provide insights into the entry/exit time of ABFT in the GSL, along with potential feeding locations while they are in the GSL (**Figure 5**). We obtained data from a post-release mortality study on ABFT where 52 fish were tagged between 2017-2018. Specifically, 12 and 40 were tagged in 2017 and 2018, respectively. Most fish were tagged off the coasts of Prince Edward Island and Nova Scotia, though one was tagged off the coast of Newfoundland (**Figure 6**).

To evaluate time spent in the GSL, receiver detections were used from 2019 and not previous years (2017-2018). Detections prior to 2019 represent years where fish were tagged and thus the majority of fish tagged in 2018 do not have entry times, as they were already present in the GSL.

In 2019, 21 out of the 52 tagged ABFT returned to the Gulf of St. Lawrence. Many fish (18/21) showed activity that indicates entry and exit dates for the GSL, which was represented by more than one detection from the Cabot Strait/Belle Isle Bay receiver line at least 1 month apart. Entry into the GSL was most common in June (6 fish) and August (8 fish), but also occurred in July (3 fish) and September (1 fish). Exit dates were most common in October (9 fish) and November (8 fish), but also occurred in September (1 fish). Between the entry and exit dates, fish tended to be detected off the coast of Nova Scotia (Cape Breton), New Brunswick (Miscou, Baie-des-Chaleurs), Quebec (Gaspe, Baie-des-Chaleurs) and Prince Edward Island (North Lake, North Cape) (**Figure 7**). When fish were present in the GSL, 7 of 21 entered the Baie-des-Chaleurs, 2 of which were present when the 2019 herring acoustic survey was taking place (**Figure 8**).

We also received data from Barbara Blocks' long-term tagging program. Dr. Block provided data from fish that entered the Baie-des-Chaleurs from 2013-2020. In total, 21 fish from tagging efforts in the U.S. were detected in the Baie-des-Chaleurs, between 2013 and 2020 (**Figure 9**). In 2019, 6 fishes were detected in the Baie-des-Chaleurs, and of these individuals three entered the GSL in June and July respectively while five exited the GSL in October and one in November (**Figure 10**).

Data from Dr. Blocks' tagging suggests that 21 tagged fish entered the Baie-des-Chaleurs between 2013-2020. While sample sizes are small for most years, 6 fish entered the Baie-des-Chaleurs in 2019 and results suggest that most activity (receiver detections) from tagged fishes occurred in July (**Figure 10**). Specifically one fish had ~ 19 detections and another 11 detections in July (**Table 1**). Overall, tagged fishes were detected in the Baie-des-Chaleurs during survey periods in 2013 (3 fishes), 2014 (1 fish), 2018 (1 fish) and 2019 (2 fishes).

Results from the Canadian- and U.S.-tagged tuna detections suggests that ABFT enter and exit the GSL in months that coincide with fishing activity in the GSL. In addition, some tagged fish were present in the Baie-des-Chaleurs during the survey periods. Despite these detections, the acoustic index of abundance reached record low values in 2018 and 2019. While sample sizes are small, and thus it not possible to draw conclusions regarding changes in timing of activity in the Baie-des-Chaleurs, results from the U.S. tag detections suggests that there may be a shift to earlier activity (July) in the Baie-des-Chaleurs in comparison to previous years. While fish are still detected in September and October in 2018-2019, the bulk of the activity appears to occur in earlier in the year, falling well outside of the survey period. Anecdotes from fishermen corroborate this finding, who have noted that fish are more active in the Baie-des-Chaleurs in July (R. Jones, pers. comm.). This may suggest that tuna are more likely to spend time in the Baie-des-Chaleurs outside of the survey period, which could contribute to the low index values in recent years. If tuna have shifted their activity and the timing of their activity in the Baie-des-Chaleurs, the forces driving this change may be related to changes in prey availability and the environment.

1.3 Prey species abundance

Hypothesis: Changes in prey availability (herring, mackerel, capelin) have impacted the Baie-des-Chaleurs acoustic index.

Herring abundance in the GSL has been unstable since the early 1990's, declining in 2000 and has been relatively low since. In recent years, (2018-2019) herring biomass, as estimated by the acoustic survey, has been at record lows, below 0.0125 kg/m^2, coinciding with record low ABFT index values (**Figure 3**). Previous analysis (Gillespie *et al*. 2020), along with interviews with fishermen in the GSL indicates that there is a strong relationship between ABFT presence and herring schools. This may have implications for the index as ABFT likely enter the Baie-des-Chaleurs to feed on herring and the absence or "record low" value may result in tuna foregoing foraging in the Baie-des-Chaleurs. We have begun assembling abundance indicators for other BFT prey species (mackerel, capelin) to assess patterns at varying spatial and temporal scales in the GSL and this work is ongoing.

1.4 Environmental variables

Hypothesis: Changes to local and regional environmental conditions have impacted the Baie-des-Chaleurs acoustic index.

Bluefin tuna diving behavior and distribution patterns are affected by environmental variables including sea surface temperature (SST) and water-column structure (Block *et al*. 2001, Lawson *et al*. 2010, Vanderlaan *et al*. 2014, Walli *et al*. 2009). We examined water temperature patterns at two spatial scales: at the transect level (SST, thermocline) and regional GSL level (GSL SST anomaly, timing of GSL mean SST dropping to 10°C, volume of cold intermediate layer). Transect level SST appeared to have little relationship with BFT index values (**Figure 11**), however, regional-scale SST anomaly data indicates that 2018 and 2019 were cooler years, coinciding with low BFT index values (**Figure 12**). Our interviews with fishermen indicate a potential relationship between cooler temperatures and earlier BFT departures from the GSL. To further examine this hypothesis, we compared the timing of GSL cooling to 10°C to index values and see some covariance between this timing and BFT index patterns (**Figure 13**). We observed no obvious relationships between either volume of GSL cold intermediate layer or thermocline depth and index values (**Figures 14, 15**). The relationship between BFT abundance in the Baie-des-Chaleurs and environmental variables will require a more thorough examination within a statistical modeling framework. This work is ongoing.

2. Discussion

Our analysis suggests that vessels effects are likely not a contributing factor in recent declines in the index. We observed no significant negative effects that could be attributed to changes from the catamaran style vessel to the monohull fishing vessel configuration.

Results suggest that ABFT may be shifting the timing of their activity in the Baie-des-Chaleurs to earlier months (July). This shift is likely a response to record low herring biomass (September-October) and changes to the local environment (cold temperatures) in the Baie-des-Chaleurs.

Atlantic herring have historically been a significant prey species for ABFT feeding in the Gulf of St. Lawrence, however, their biomass has been low (since 2000's) and highly unstable in recent years (2010-2019). As a forage fish species with high lipid content, herring provided tuna with the energy and nutrients to make long migrations; however, given the current uncertainty of obtaining adequate nutrients from herring alone, tuna may be shifting their diet to other forage species. Mackerel are a secondary high lipid prey species, however, their populations in the Gulf of St. Lawrence are extremely low as well. Isotope analysis for fish landed in the GSL suggests that sandlance, mackerel and herring are important prey species in the GSL (Busawon *et al*, in prep) and changes in abundance in these prey could be impacting foraging patterns in BFT. Past research suggests that this shift to more abundant species like sand lance and capelin is not unexpected. Staudinger et al. (2020) suggest that the abundance of herring and sand lance oscillate out of phase, as a top-down mechanism. Atlantic herring and mackerel are known to feed on larval sandlance, and thus when the abundance of herring and mackerel is low, sandlance become more abundant (Staudinger et al., 2020). Work on feeding ecology and prey abundance patterns in the GSL is ongoing.

Survey timing and presence of Bluefin tuna in the Baie-des-Chaleurs are possibly mismatched. Future work will also review the potential to use acoustic data from other Atlantic regions to develop indexes covering a greater proportion of the ABFT distribution in Eastern Canadian waters and discuss adding an acoustic survey component to existing ecosystem surveys.

The Bluefin Tuna Working Group has a number of options available when considering the index as a future assessment input:

1. Use the index "as-is". This assumes that the index is representative of stock abundance trends. There are two potential approaches for the coefficient of variation associated with index values:
   a. Use CV as currently calculated for each year.
   b. Assign a higher CV to the entire time series or just the 2018 and 2019 index years.
2. Discontinue use of the index, assuming that it is not representative of stock abundance trends.
3. Split the index from 2018 onward, assuming there was a regime shift in the Baie-des-Chaleurs. This option is most similar to the approach used in the 2020 Bluefin assessment where the 2018 value was dropped.
4. Use a model-based standardization that accounts for environmental and prey covariates, similar to Gillespie et al. 2020.
5. Set a prey abundance threshold value that determines whether the index value is included in the assessment. For example, if the annual southern GSL herring biomass estimated from the survey is less than 0.25 kg/m^2 the Bluefin index value would not be used.

After discussions within the group during the April 2021 Intersessional Meeting of the Bluefin Tuna Species Group, the final recommendation was to use option 3. This involves splitting the index into 1994-2017 and 2018-present, with the caveat that historical use of the index will be revisited after the 2021 assessment and when future analysis of the index has been conducted.

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Table 1. Individual fish detections in the Baie-des-Chaleurs between 2013-2019. Individual fish are not similar through years, however, do illustrate individual tagged tuna (individual box) and their monthly detections from July-October.

Year	Month	Number of monthly detections for individual tagged Bluefin tuna						
2013	July August September October	12 0 0 0	3 2 1 12	1 5 1 0	3 8 5 0	0 0 2 2		
2014	July August September October	6 4 1 7	0 0 0 1					
2015	July August September October	1 0 0 0	4 0 0 0					
2016	July August September October	0 0 3 0	1 0 5 0					
2017	July August September October	0 2 0 0	1 5 0 0					
2018	July August September October	3 3 1 0	0 0 1 0	1 0 0 0	0 5 0 0			
2019	July August September October	1 0 0 0	0 8 5 0	19 0 0 0	0 1 0 0	11 0 0 0	7 0 1 1	1 0 0 0

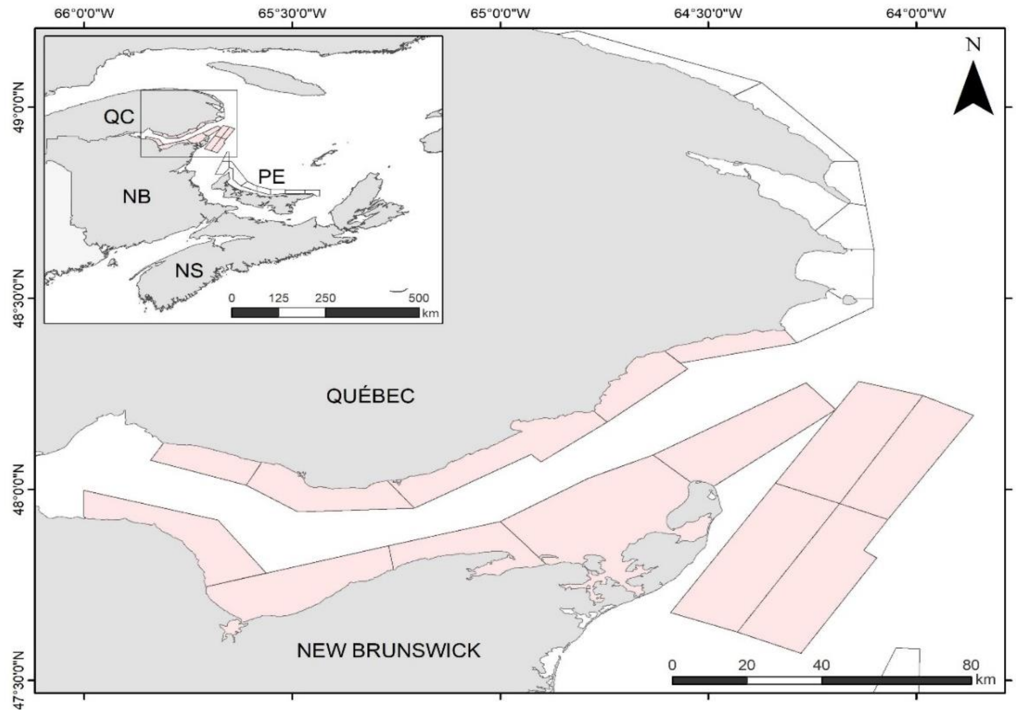

Figure 1. Map of survey area in the southern Gulf of Saint Lawrence, in the Baie-des-Chaleurs. Boxes in pink represent strata that have been included in the acoustic index, while boxes in white, which have not been consistently surveyed over the years, have been omitted from analysis.

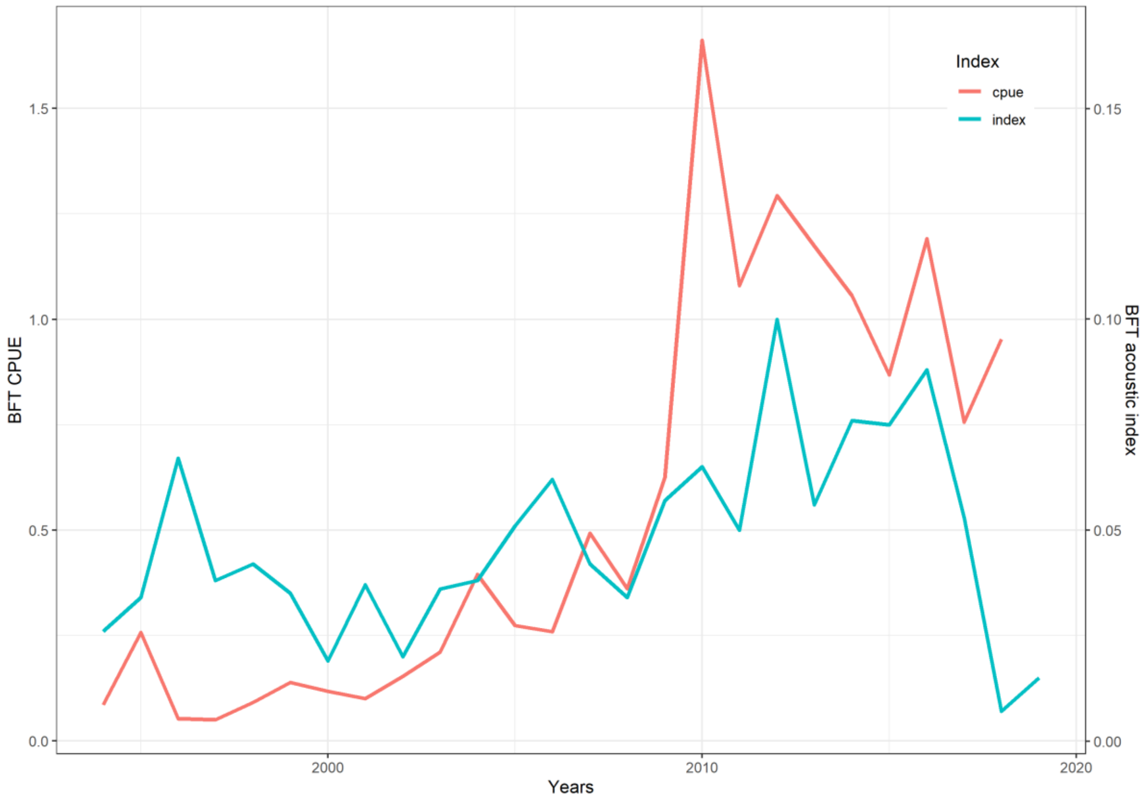

Figure 2. Atlantic Bluefin tuna abundance time series using fishery-dependent CPUE (Hanke, 2019) and fishery-independent acoustic data (stratum area weighted average # of tuna/km) for the Gulf of Saint Lawrence and Baie-des-Chaleurs, respectively.

Figure 3. Atlantic Bluefin tuna abundance index using fishery-independent acoustic data (area weighted average # of tuna/km) in comparison to herring biomass (kg/ m^2) for the Baie-des-Chaleurs, Gulf of Saint Lawrence.

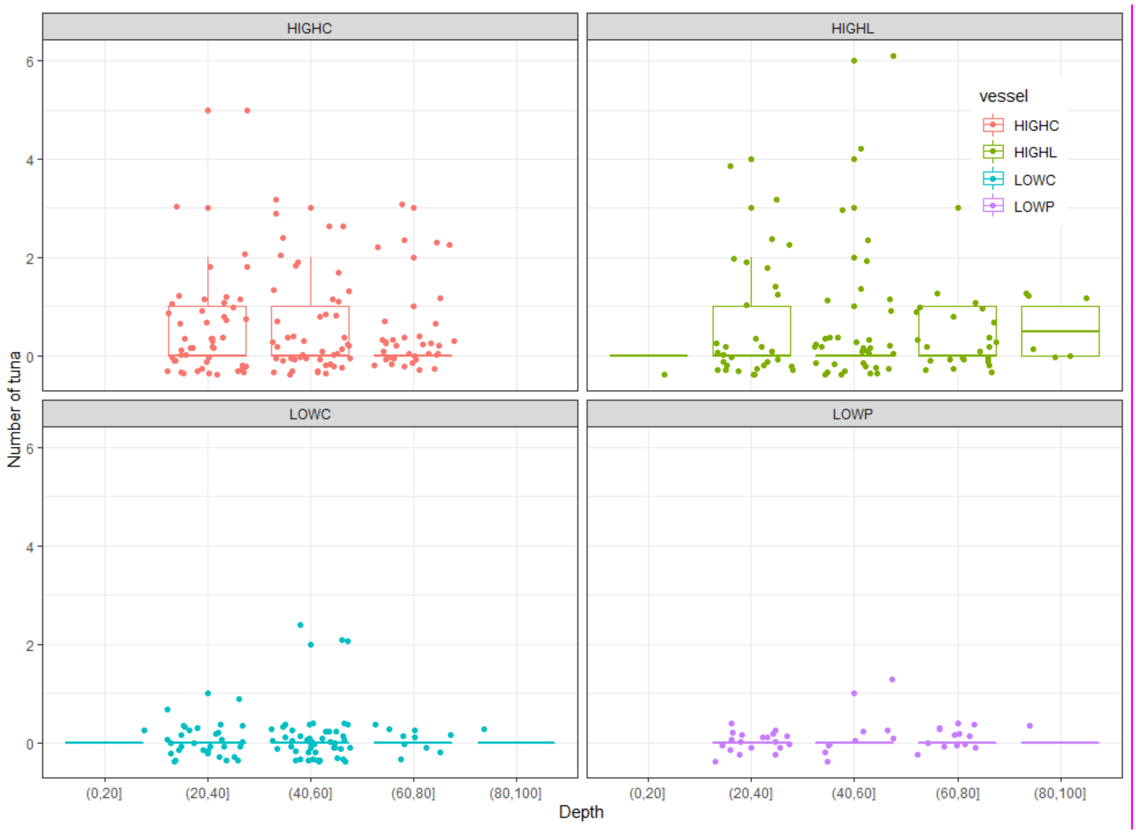

Figure 4. Boxplots for the number of tuna detected across average transect depth bins (0-100 meters) in high and low index years using the Creed, Leim, and Perley. High index years were 2014 using the Creed (HIGHC) and 2015 using the Leim (HIGHL), while low index years were 2018 using the Creed and Perley (LOWC/LOWP).

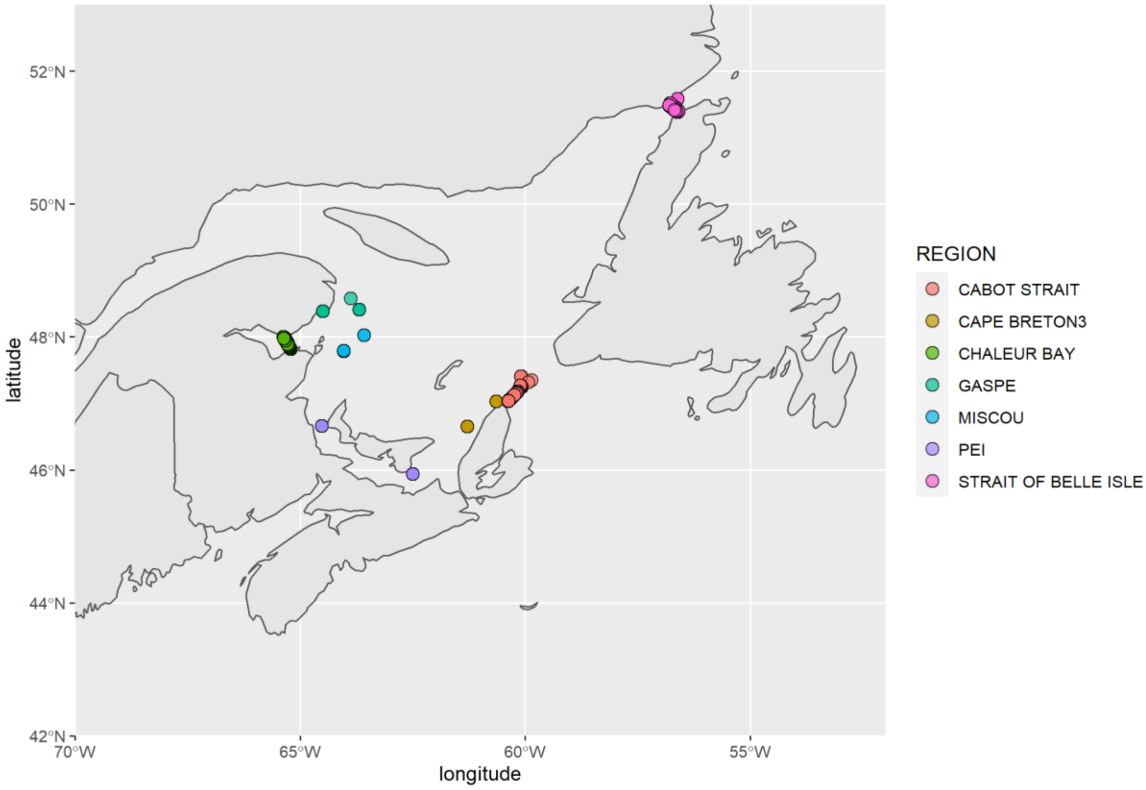

Figure 5. Receiver locations in the Gulf of St. Lawrence where tagged Bluefin tuna (52 fishes) have been detected in a post-release mortality study.

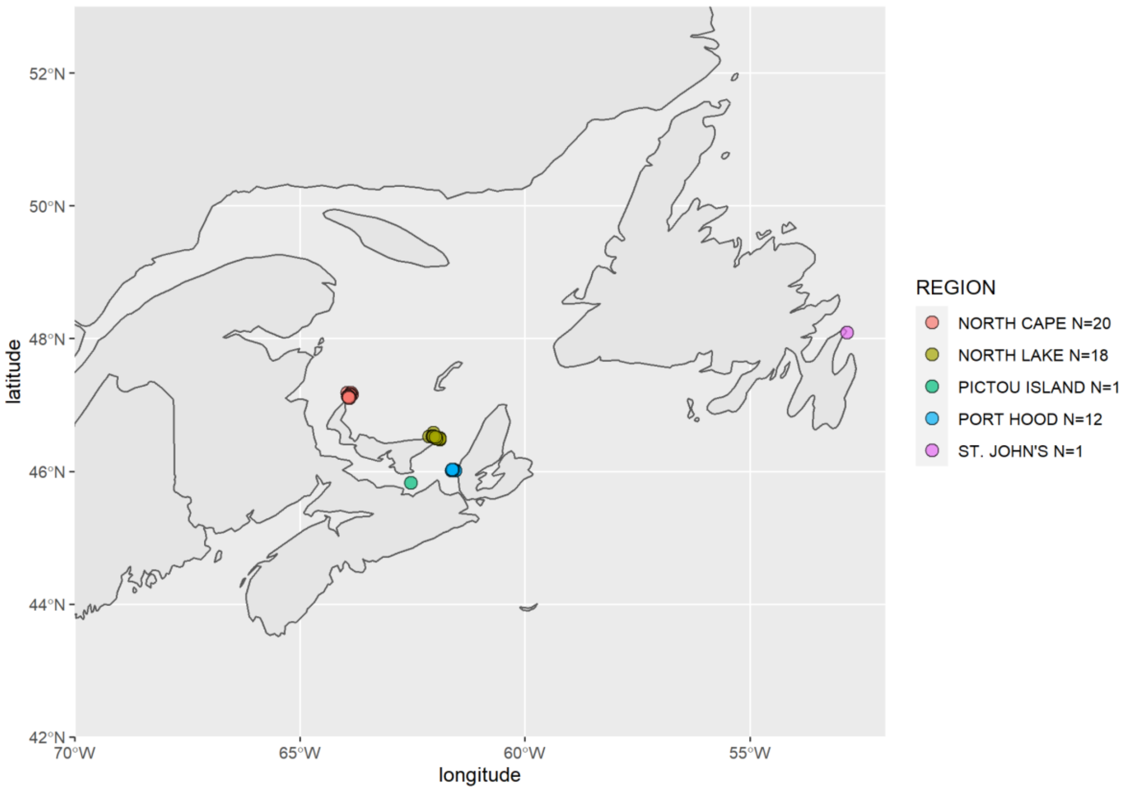

Figure 6. Release locations of all 52 Bluefin tuna tagged for a post-release mortality study. Sample sizes for each location indicated in the figure legend relative to each location in the Gulf of St. Lawrence.

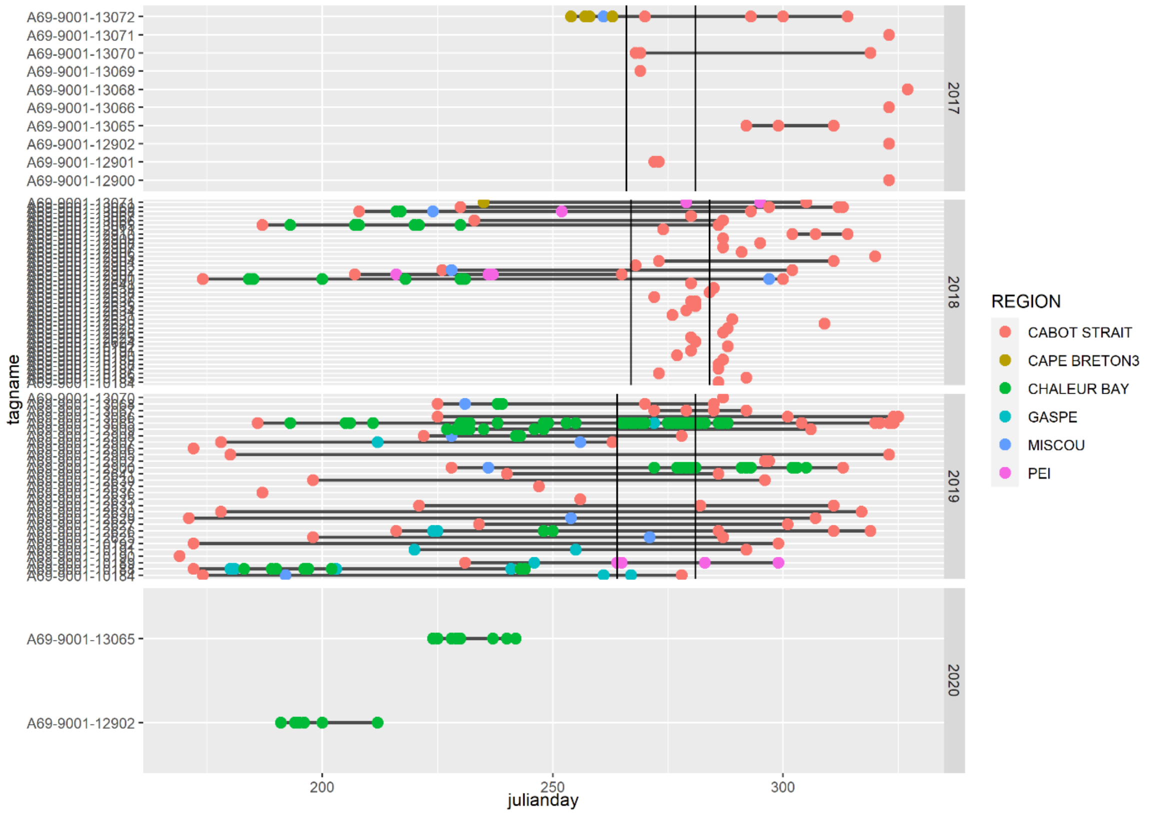

Figure 7. Receiver detections for individual tagged Bluefin tuna from 2017-2020 in the Gulf of St. Lawrence over the course of each year represented in Julian days.

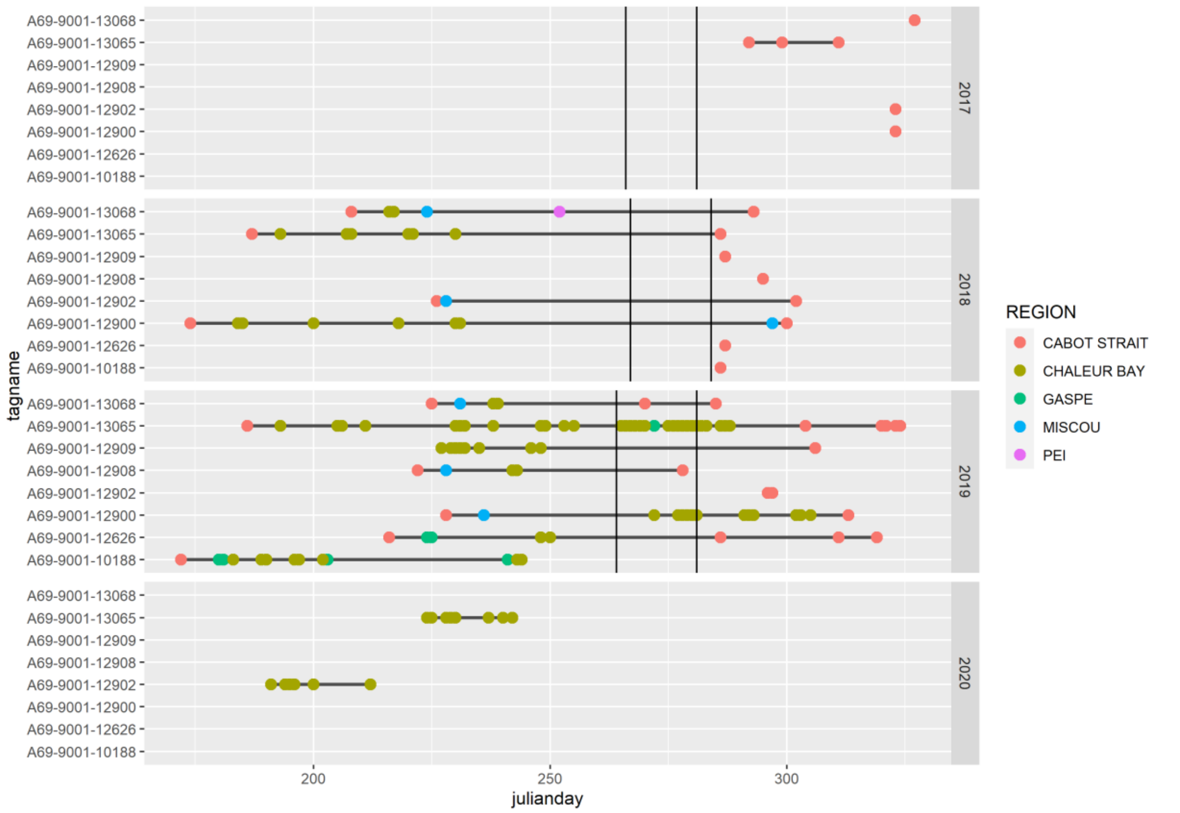

Figure 8. Receiver detections in the Gulf of St. Lawrence for individual tagged Bluefin tuna that were specifically detected in the Baie-des-Chaleurs from 2017-2020 over the course of each year represented in Julian days.

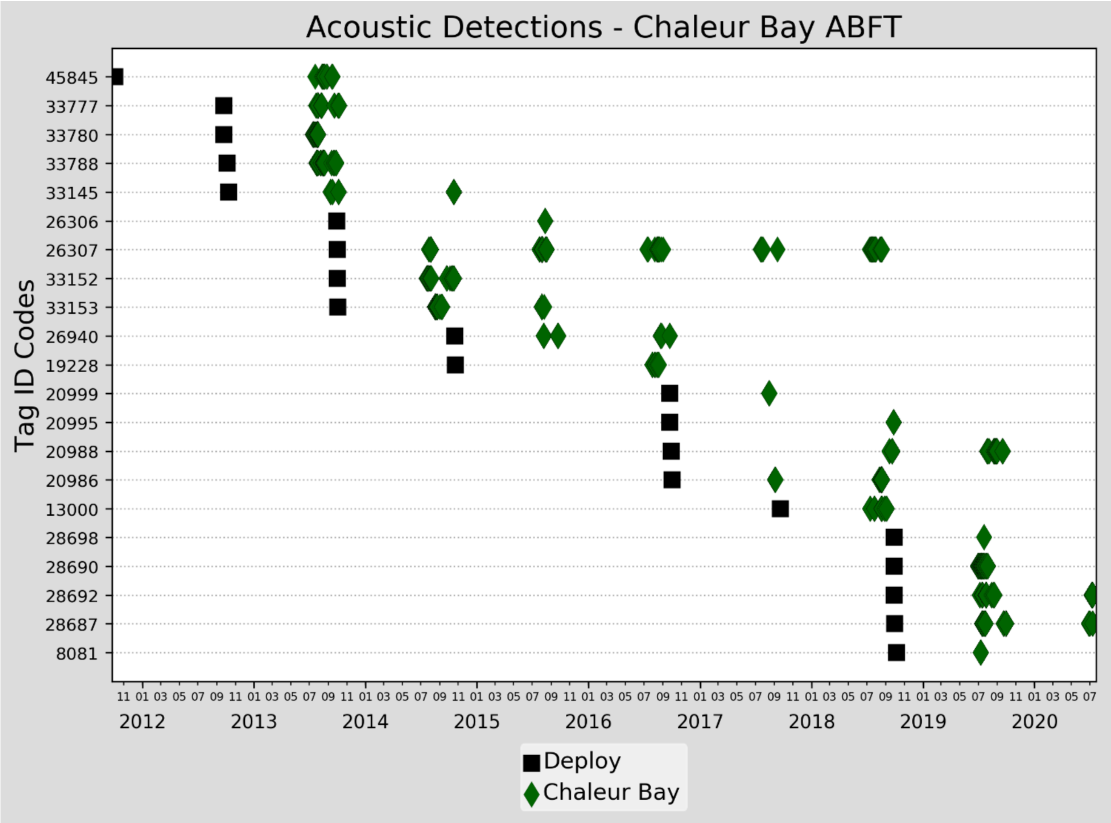

Figure 9. Tag deployment (black square) and tag detections specific to the Baie-des-Chaleurs receivers between 2012-2020 from Barbara Block's U.S. tagging.

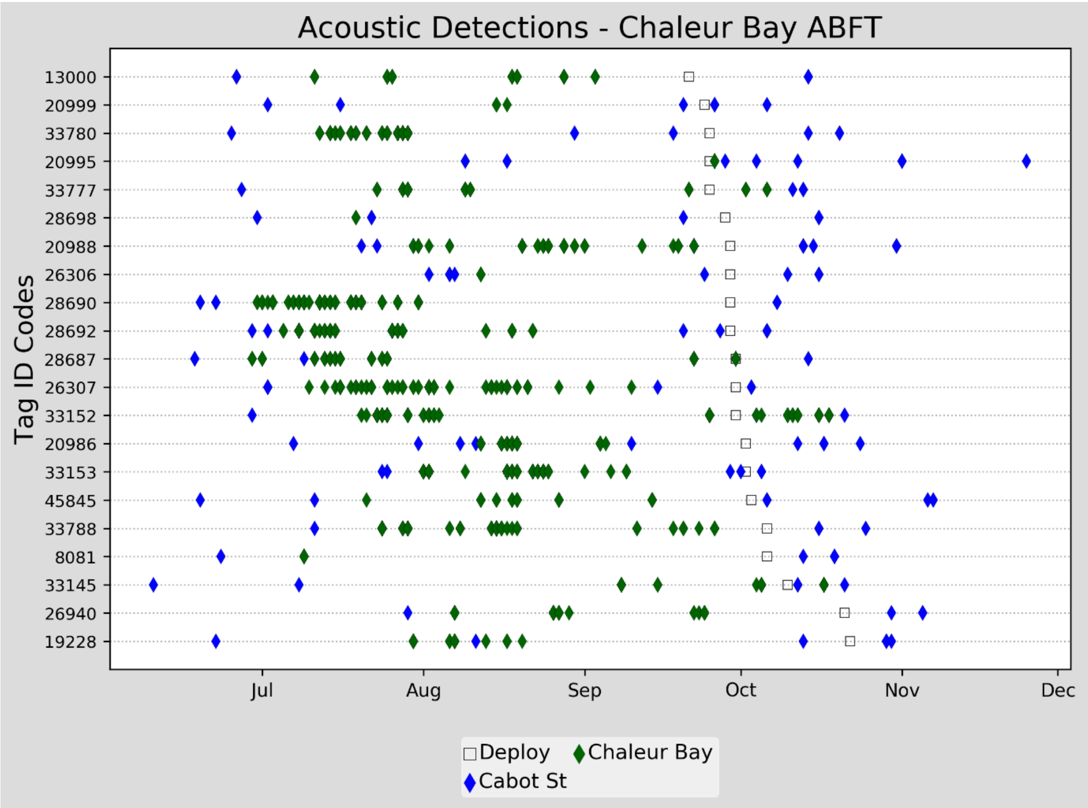

Figure 10. Receiver detections on the Cabot Strait and Baie-des-Chaleurs between 2012-2020 for tags that specifically entered the Baie-des-Chaleurs between 2012-2020.

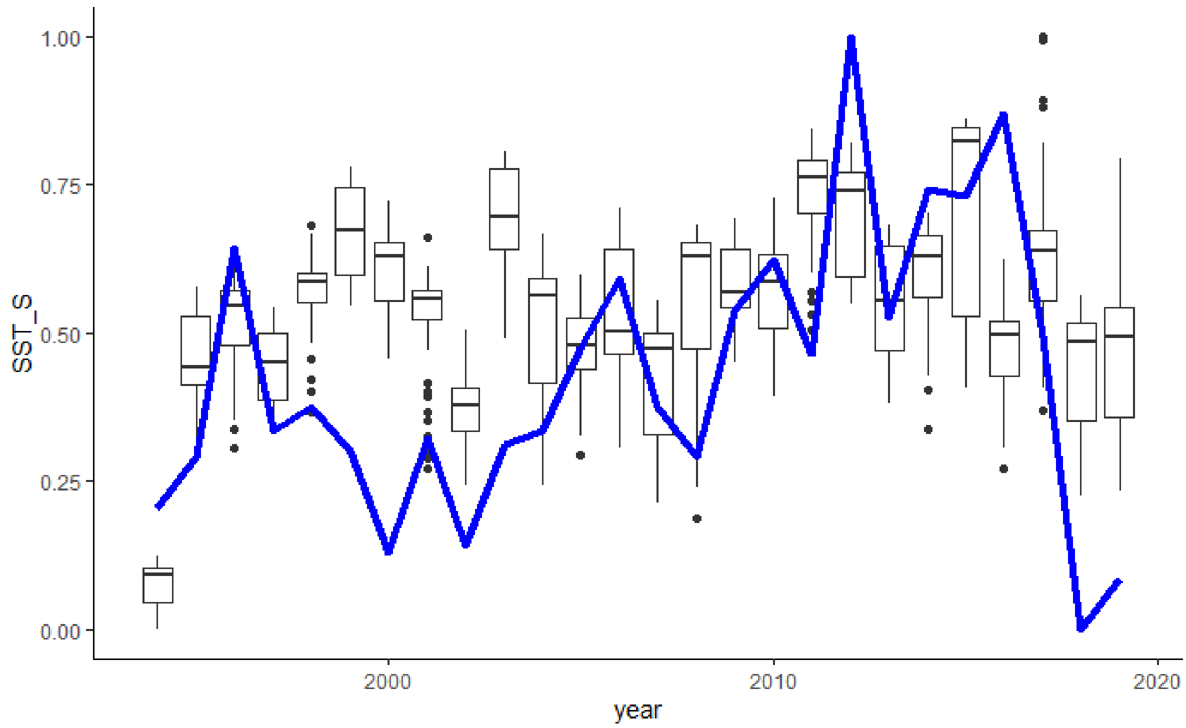

Figure 11. Transect SST (boxplots) and Bluefin tuna acoustic index of abundance (blue line). Both series normalized.

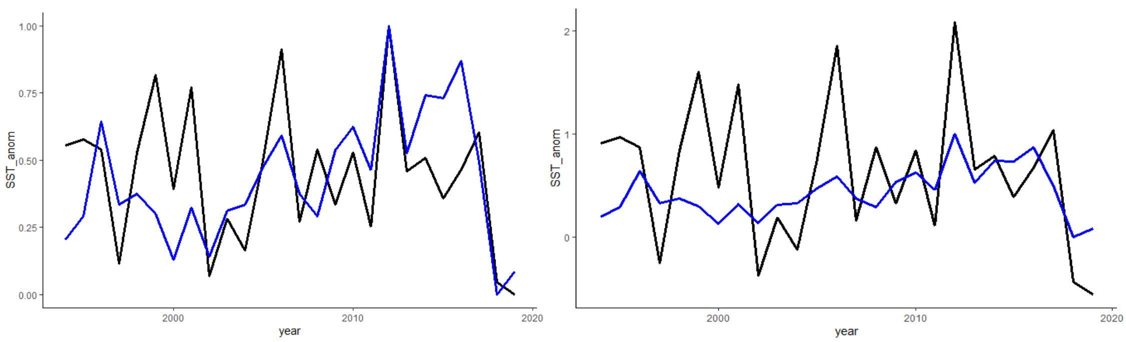

Figure 12. Regional SST anomaly (black line) and Bluefin tuna acoustic index of abundance (blue line). Plot on the left has both series normalized. Plot on the right has absolute temperature anomaly values and normalized BFT abundance values.

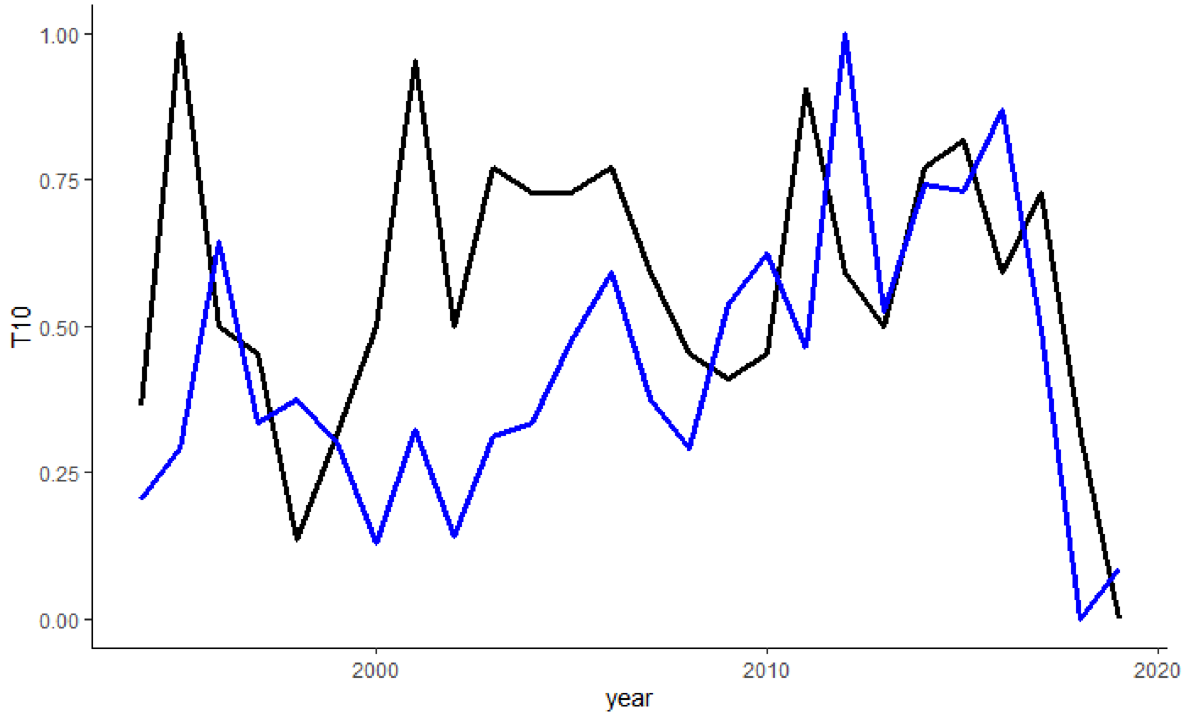

Figure 13. Number of weeks into the year that the mean GSL SST drops to 10°C (black line) and Bluefin tuna acoustic index of abundance (blue line). Both series normalized.

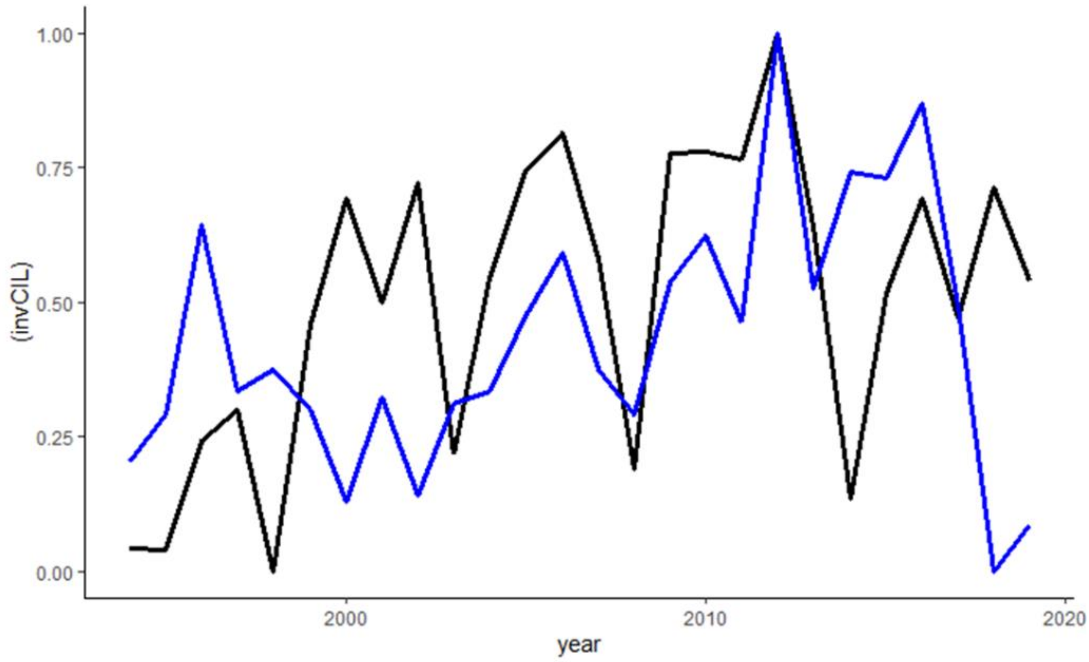

Figure 14. Volume of GSL cold intermediate layer (black line) and Bluefin tuna acoustic index of abundance (blue line). Both series normalized. CIL values are 1 minus the normalized CIL value.

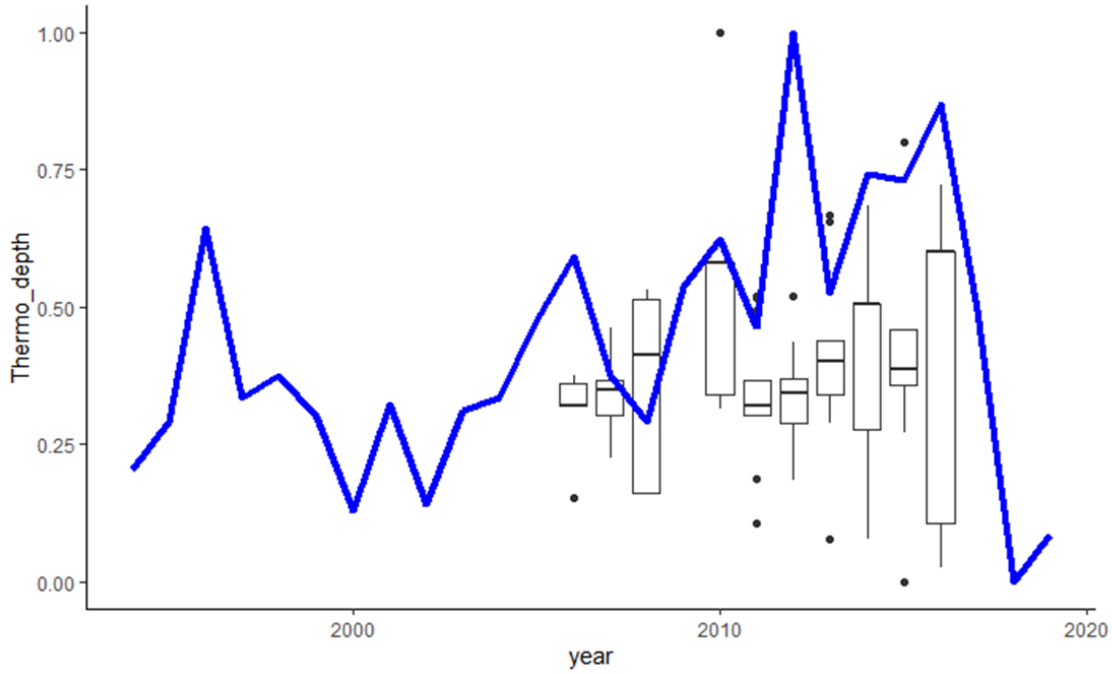

Figure 15. Transect thermocline depth (boxplots) and Bluefin tuna acoustic index of abundance (blue line). Both series normalized.