INDICES OF STOCK STATUS FROM THE CANADIAN BLUEFIN TUNA FISHERY: 1981 TO 2013

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SUMMARY

The catch of Atlantic bluefin tuna from the Canadian rod and reel, tended line and harpoon fisheries is standardized for two geographically distinct areas: south west Nova Scotia and the southern Gulf of St. Lawrence. Nominal and standardized series from the two areas suggest an increasing trend in abundance in the southern Gulf of St. Lawrence while the trend for southwest Nova Scotia is a decline that appears to be linked to the fact that the scope of the data has not changed in accordance with the redistribution of the fishing effort. Another consideration is that the size composition of the catch has shifted towards larger individuals over the past 5 years.

RÉSUMÉ

La capture de thon rouge de l'Atlantique par la pêcherie canadienne de canne et moulinet, de ligne surveillée et au harpon est standardisée pour deux zones géographiques différentes: le Sud-Ouest de la Nouvelle-Écosse et le Sud du golfe du Saint-Laurent. Les séries nominales et standardisées de ces deux zones suggèrent une tendance croissante de l'abondance dans le Sud du golfe du Saint-Laurent alors que la tendance du Sud-Ouest de la Nouvelle-Écosse est à la baisse, ce qui semble être lié au fait que la portée des données n'a pas changé avec la redistribution de l'effort de pêche. Il faut également tenir compte du fait que la composition par taille de la capture a été marquée par des spécimens plus grands au cours des cinq dernières années.

RESUMEN

Se estandarizaron las capturas de las pesquerías canadienses de atún rojo de caña y carrete, barrilete y arpón, para dos zonas geográficas diferenciadas: suroeste de Nueva Escocia y parte meridional del golfo de San Lorenzo. La serie nominal y estandarizada de las dos áreas sugería una tendencia ascendente en la abundancia en el golfo de San Lorenzo meridional, mientras que la tendencia para la parte sudoccidental de Nueva Escocia es un descenso que parece estar vinculado con el hecho de que el alcance de los datos no ha cambiado de conformidad con la redistribución del esfuerzo pesquero. Otra consideración es que la composición por tallas de la captura ha cambiado hacia ejemplares más grandes en los últimos cinco años.

KEYWORDS

Tuna fisheries catch rates, Composition,
Hurdle model, Bluefin tuna, Rod and reel, Catch standardization

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1. Description of the data source

1.1 Description of the fishery and target species

The main Canadian commercial Bluefin tuna fisheries occur off the coast of southwestern Nova Scotia (SWNS) and in the southern Gulf of St. Lawrence (sGSL), targeting fish migrating into Canadian waters between July and November. The spatial distribution of commercial catches in the Canadian EEZ in 2013 has been consistent with that of previous years (**Figure 1**). Catches for the SWNS fishery are localized along the northern edge of Georges Bank, the Hell Hole and the Bay of Fundy, while the sGSL fishery typically focuses on waters north of Prince Edward Island and west of Cape Breton Island (**Figure 1**). Outside of the these two fisheries, some catches occur along the east coast of Nova Scotia, with the majority being conducted around St. Margaret's Bay/Halifax and Canso areas (**Figure 1**).

Prior to 2004, the majority of trips for the SWNS fishery took place during the month of August and September, but in recent years the bulk of the fishing has taken place during September and October (**Figure 2**). This fishery has been dominated by rod and reel catches since the early 2000s, with smaller contributions by tended line and electric harpoon; tended line was the dominant gear during the early years of the series (**Figure 3**). The Scotia-Fundy (SF) home fleet accounts for 50% of the catches in SWNS waters and since 2008 this proportion has increased to 75% due to fewer trips made by ex-sector fleets (GNS, GNB, PEI, PQ) (**Figure 4**, **Figure 5**).

In the sGSL fishery, the majority of activity is attributed to P.E.I. and Nova Scotia (GNS) home fleets (**Figure 4**). Although historically the catches in the sGSL fishery were distributed throughout the months of August, September and October, fishing seasons throughout the 2000s have been heavily skewed towards either August or October (**Figure 2**, **Figure 6**). Following the implementation of an individual transferrable quota-like system in 2011, the fishing season expanded to encompass all three months equally. The 2013 season, however, is indicating a return to a compressed fishing season, with 70% of the trips occurring during the month of September (**Figure 2**). Similar to the SWNS trend, the sGSL fishery has also witnessed a transition from primarily tended line fishing to rod and reel (**Figure 3**).

1.2 Ecosystem considerations

The abundance and condition of Bluefin Tuna in Canadian waters will depend on many factors; particularly the availability of their prey. Atlantic Bluefin Tuna are seasonal migrants to feeding grounds in Atlantic Canadian waters (Scott and Scott, 1988). Bluefin in the northwest Atlantic feed on smaller fish, depending on the local species available, including; Atlantic Herring, Atlantic Mackerel, Sand Lance, Bluefish, Silver Hake and squid (Bigelow and Schroeder, 1953; Chase, 2002; Dragovich, 1970). Commercial catch and trawl survey indices indicate that Atlantic Herring and Atlantic Mackerel are principal pelagic prey for Bluefin Tuna in the Gulf of Maine, and cephalopods (squid) are an important secondary source of prey (Chase, 2002). The Canadian fishermen report that Bluefin are mainly feeding on Herring and Mackerel, although recent observations from the fishery suggest that Bluefin are opportunistic predators, with varied prey such as American Lobsters and Hagfish apparent in the stomachs of tuna collected off southwest Nova Scotia. Bluefin Tuna in northern Newfoundland coastal waters were recently observed to be feeding on large schools of Saury.

There are two stocks of Atlantic Herring in Canadian waters that correspond with areas of Bluefin Tuna fishing. The 4VWX Herring corresponds with the Bluefin fishery in southwestern Nova Scotia, the Bay of Fundy and the Scotian Shelf. The Herring in 4T correspond with the Bluefin fishery in the southern Gulf of Lawrence north of Prince Edward Island and to the west of Cape Breton. The 4T herring stock is further divided into spring and fall spawning components. Given the timing of aggregations of both Bluefin tuna and Herring in the southern Gulf, it is likely that the fall component is the most consequential in the Bluefin diet.

The Herring spawning component for southwest Nova Scotia and the Bay of Fundy has seen a 32% reduction in spawning stock biomass from an average of 551 kt from 2001-2004 to 377 kt average from 2005-2010 (long term average 1999-2013, 454 kt; **Figure 7**) (DFO, 2014a). The overall acoustic biomass estimates increased by 44% in 2011 (over 2010) and again in 2012 (6% over 2011), which moved the stock above the long term average of 454 kt (DFO, 2013). However, the overall acoustic biomass estimates decreased sharply (from 476 k t to 342 kt, -39%) in 2013 (DFO, 2014a), shifting the biomass estimate to 24% below the long term average. Science advice to management is to continue to exercise caution. Average mean weight at age has declined every decade since the 1970s, with the 2012 value (not an average) the lowest on record (DFO, 2013). The productivity of the stock is reduced with the declining mean weight at age of the fish. In the past it has been observed that Herring can avoid detection by staying in deeper, cooler waters where they are not vulnerable to weirs and less vulnerable to purse seines, although presumably still available for bluefin tuna.

The spring and fall spawning Atlantic Herring in the southern Gulf of St Lawrence are managed as two separate components. The biomass of the spring spawning component (22,280 t) is just above the precautionary approach limit reference point (22,000t) placing it in the cautious zone (DFO, in press). The spring spawning population biomass remains at low levels compared to earlier in the time series, but has increased slightly every year since 2006 (**Figure 8**). However, as noted above, the spring spawning component is likely less important for Bluefin tuna than the fall component. The fall spawning component has significantly more biomass than the spring component. Two models that differ in catchability assumptions were used to assess the status of the fall spawning component, with no clear choice between them. Both models indicate similar trends with a peak in age 4+ spawning stock biomass in 2009 and ongoing declines since, but significantly different estimated biomass (DFO, in press). Model 1 estimates biomass (98,000 t) to be in the cautious zone (**Figure 9a**), while Model 2 estimates a much higher biomass (182,800 t) that is just above the upper stock reference level (172,000 t) and in the healthy zone (**Figure 9b**). Similar to the southwest Nova Scotia Herring, both the spring and fall spawning components are showing decreased weight at age. The causes of these decreases are unknown. Observations and opinion from Industry feedback suggests that the spring spawning component has remained stable since 2011, while the fall spawning component has been decreasing since 2006.

Landings of Atlantic mackerel in NAFO subareas 3 and 4 (which includes the range of Bluefin Tuna in the Canadian Atlantic) increased substantially in the 2000s to reach an historic high of 54,621t in 2005, before landings dramatically declined to 11,400 t in 2011, 6,468 t in 2012, and 7,431 t in 2013(DFO, 2014b). Similar decreasing trends in landings are also occurring in the United States. The index of spawning biomass (measured by egg surveys) declined between 1993 and 1998, before an increase resulting from a strong 1999 year class. Following the strength of the 1999 year class, the spawning biomass index declined again to reach historic lows since 2005; the biomass estimates for 2012 and 2013 are the lowest in the historical time series (**Figure 10**) (DFO, 2014b). The declines in Atlantic mackerel abundance are caused by unsustainable fishing mortalities and a lack of recruitment. Despite the estimated declines, Bluefin Tuna in coastal Newfoundland waters have recently been observed feeding on Atlantic mackerel.

Research on the diet of Bluefin Tuna in the northwestern Atlantic has shown that squid is an important prey item (Bigelow and Schroeder, 1953; Chase, 2002; Dragovich, 1970). Anecdotal comments from Canadian fishermen indicate that squid was being seen in very high numbers in 2012; however, there is unfortunately no stock assessment or research available for the status of squid in Canadian waters.

The southern Gulf of St Lawrence has seen a major shift from a large groundfish and forage fish dominated system, to one dominated by small bodied forage fish. Although the groundfish fishery has been under moratorium since the mid-1990s, increased natural mortality is preventing the groundfish from rebuilding, thus maintaining the southern Gulf as a forage fish dominated system (Dufour *et al*., 2010). Between 1985 and 2008, the surface waters of the Gulf of St Lawrence have seen an average increase in sea surface temperature of 2ºC (Galbraith *et al.*, 2009). However, this is a short time series for warming trends and older records need to be reviewed to determine if this is part of a longer term warming trend. The cold intermediate layer (200-300m) was exceptionally warm from the late 1960s until the early 1980s, followed by very cold temperatures from 1986 to 1998 (DFO 2012). Temperatures at these depths have since returned to the long term average values. The impacts of these changes on Bluefin Tuna in this area are unknown at present, although the effects of such changes on bluefin tuna distribution and abundance are currently being investigated by Fisheries and Oceans Canada.

The Scotian Shelf has also seen structural shifts in the ecosystem as a result of changing environmental conditions and human activities (Worcester and Parker, 2010). This ecosystem has seen a major increase in the abundance of seals, benthic macroinvertebrates, phytoplankton and small pelagic fish, accompanied by decreases in groundfish and zooplankton. More recently, phytoplankton and zooplankton abundance levels are returning to their long term averages. The surface water temperature in the Gulf of Maine and along the Scotian Shelf shows high levels of variability with no discernible trend. A gradual cooling of deeper water was seen on the eastern Scotian Shelf during the same time period as the exceptionally cold intermediate layer in the Gulf of St Lawrence (mid 1980s to 1990s), but this was not observed on the western Scotian Shelf. As with the ecosystem changes in the southern Gulf of St Lawrence, it is unclear what the impact of these changes are on bluefin tuna.

The southern Gulf of St Lawrence, Scotian Shelf and southwestern Nova Scotia are all areas subject to high human impact (oil and gas exploration, shipping, fishing). Other threats include the impacts of aquatic invasive species, ocean acidification and a wide suite of contaminants. Research in these is ongoing and the impacts on different species, including Bluefin Tuna, and the ecosystems as a whole are unknown.

1.3 Available statistics and reporting requirements

Detailed trip information for the Canadian bluefin tuna fishery comes from log documents filled out by the fisherman at the end of every trip. The submission of logs has been mandatory since 1994, with the requirements extended to include zero-catch trips in 1996. The log contains information on trip catch (number and total weight of fish), catch location (NAFO area and/or latitude and longitude), effort (hours fished), date, gear characteristics, home fleet, and, in the SWNS fishery, weight of other species caught. While unloading, the log document is reviewed by an independent Dockside Monitor for completion and accurate individual size information is recorded (length and weight for GSL, weight for SWNS).

This system is designed to provide 100% coverage of logs and individual fish sizes, though small variations in coverage (<3%) can exist in a given year. The information provided by this system is considered representative of fishing activity in the Canadian EEZ.

1.4 Variables used in the development of the index, including variables related to targeting

Southwest Nova Scotia index data series includes trip-level catches dating back to 1988 and has been limited to months August, September and October. The dataset is limited to catches by rod and reel, tended line and electric harpoon gears, made within the area encompassed by NAFO 4X, 5Y and 5Z. The fleets involved in the SWNS fishery include the Scotia-Fundy home fleet and ex-sector fleets like PEI, Gulf Nova Scotia, Gulf New Brunswick and Province of Quebec.

The southern Gulf of St. Lawrence fishery is prosecuted by fleets from Quebec, P.E.I, Newfoundland, Nova Scotia and New Brunswick homeports. The P.E.I. and Nova Scotia fleets are the largest of the five and have fished regularly since 1981 (**Figure 4**). The possibility of fleets fishing in distinct geographical areas and having different fishing practices required that the catches be standardized by homeport. Newfoundland fleets were dropped from the analysis due to a lack of data.

The two main gears used in the southern Gulf of St. Lawrence were rod and reel and tended line with the former replacing the latter over the time course of the series (**Figure 3**). The data for the temporal explanatory variable month was truncated to include only fishing from August to October because fishing outside this time window was rare. Lastly, an explanatory variable was introduced to capture the trend in fishing season length by fleet, gear and month.

1.5 Size, age range and condition of the fish that the index applies to

Round weights in the southwest Nova Scotia fishery increased in their range during the late 2000s, and show a general increase in mean weight since 2002 (**Figure 11**). The 2013 season had a mean round weight of 251 kgs (25^{th} and 75^{th} percentiles at 179 kgs and 319 kgs respectively), exceeding the series mean of 172 kgs and making it the highest mean on record for this fishery. Since 2000 the Gulf of St. Lawrence round weights have been at or below the series mean. Weights were following an increasing trend throughout the early 2000s (**Figure 11**) and have decreased back to 2002-2003 levels in recent years (mean of 302 kgs for the 2013 fishing season). It should be noted that annual trends in individual fish weights for each fishery can be influenced by the market and may not fully reflect the true population structure.

In both fisheries, the recent weight trends are associated with changes in the number of small fish (<272 kgs) caught. In SWNS, the number of small fish landed decreased by half between 2009 and 2013, while in sGSL the number of small fish surpassed catches of both medium (272-362 kgs) and large (>362 kgs) fish for the first time since 1981[2] (**Figure 12**). This redistribution of bluefin tuna stock components within the Canadian EEZ should be explored over a broader geographical area.

Data from the Newfoundland fleet was not included in these descriptions. It is recommended that it be included in the future as it will speak to movements in area 3LNOP and further north.

[2] Note that the low counts in the sGSL in the late 1980s and early 1990s is due to the fleet fishing ex-sector in 4X.

1.6. Changes in the fishery that might affect catch rates

The mandatory submission of logbooks was instituted in 1996 and the move from a competitive fishery to an Individual Transferrable Quota (ITQ) system began in 2004 for the southwest Nova Scotia fleet. The main fleet fishing in the southern Gulf of St. Lawrence (PEI) adopted an ITQ-like system in 2011. Market demand for a given size class of tuna has had some effect on the SWNS fishery's harvest decisions according to industry participants.

2. Methods

2.1 Data exclusions and rationale

Both the SWNS and the sGSL datasets were filtered in order to restrict the data to views established in the past. For example, in the SWNS fishery, catches made by the trapnets in St. Margaret's Bay were excluded, limiting the index to tended line, rod and reel, and harpoon gears. Catches landed by the Newfoundland fleet (ex-sector) were also removed from the SWNS data becasue these vessels are said to not behave in a manner consistent with the other fleets. Also, the data was limited to catches in August, September and October. Finally, the SWNS dataset was limited geographically to NAFO areas 4X, 5Y and 5Z (**Figure 1, Figure 13**), while excluding sub-area 4Xm and 4Xu (Halifax/St. Margaret's Bay region).

Similarly, the sGSL index was limited to two gears (Rod and Reel and Tended Line) and three months (August, September, October). Geographically, valid Gulf trips must fall within a box bounded by 68°W to 60°W longitude, and 46°N to 50°N latitude (**Figure 1, Figure 13**). Only catches made by the P.E.I., N.B., P.Q. and N.S. home fleets within this geographical area were retained.

2.2 Management regulations

There have been two major changes in the management of the Canadian Bluefin tuna fishery: 1) the introduction of mandatory log submissions in the mid-1990s and 2) the switch to an Individual Transferable Quota (ITQ) fishery in the early 2000s (SWNS) and 2010s (sGSL). Starting in 1996, mandatory log submissions provided detailed information on all trips targeting Bluefin tuna in Canadian waters, including trips with no catch; prior to 1996, this information was submitted on a voluntary basis.

2.3 Dataset used in the analysis

A summary of the data for each of the explanatory variables is given in **Table 1** for SWNS and **Table 2** for the sGSL. Catch rates and the probability of catch are given in **Table 3** and **Table 4**.

2.3.1 The effort and catch variables

In both the sGSL and SWNS fisheries, hours fished have been used as the measure of effort (Paul *et al.* 2010). Alternative measures include trip length in days, number of vessels, number of trips and length of season. Each of the alternatives is generally linearly related to hours fished and their usefulness depends on the level of aggregation of the data.

The catch variable for both fisheries was a count of Bluefin tuna caught. In the sGSL this count and the hours was aggregated by day, fleet (P.E.I., N.S., P.Q. and N.B.), month (August, September, and October) and gear type (rod and reel and tended line). The count and hours fished for the SWNS data was aggregated by trip.

2.4 Model standardization

The 2012 paper by Hanke et al. describes the model standardization used to develop the standardized indices for the sGSL and SWNS using catch data to 2011. The very same final models were adopted for the standardization of the catch data to 2013 because a strict update of the indices was requested. The earlier document is to be referred to where further clarification of the model standardization process is desired however some parts are reproduced here for the reader's convenience.

Hurdle models (i.e. delta models) were fit to both the SWNS and sGSL bluefin tuna count data. The models had two components: a binomial model to model the probability that a zero value was observed and a truncated Poisson model for the counts. The pscl package (Zeileis *et al.* 2008) allowed maximum likelihood estimates for the truncated count component and the hurdle zero component to be maximized separately. Prior to model simplification, the Poisson counts were tested for overdispersion against a complementary truncated negative binomial model for the counts using a likelihood ratio test. The model selection in both cases involved starting with as full a model as the data would allow and then dropping the least significant interactions and main effects until none could be rejected using a likelihood ratio test (Zeileis and Hothorn, 2002). Factors and interaction terms were retained if the p-value for the Chi-square statistic was between 0.5 and 0. No year effects were included in the models due to the unbalanced nature of the data across the year*factor categories and its missingness for some year*factor combinations.

The year effect was extracted from the model by averaging the predictions for all combinations of levels of the categorical variables while holding the continuous variable hours fished at the median value of 48 h for the sGSL and mean value of 24h for SWNS. Standard errors for the year effects were estimated using a bootstrap procedure in which the original records were sampled with replacement to create 500 datasets of similar size. These datasets were used to recalculate the year effects using the same component models (Vignaux, 1994).

The fully prescribed component models (zero and count) for SWNS were identical:

$$f(\text{Count,Zero}) \sim \text{year} + \text{month} + \text{home\_mgt\_area} + \text{gear\_code} + \log(\text{hours}) + \log(\text{hours})^2 + \text{month}:(\text{gear\_code} + \text{home\_mgt\_area}) + \log(\text{hours}):(\text{month} + \text{home\_mgt\_area} + \text{gear\_code})$$

The SWNS data were fit with logistic links for the count and zero models and no further reductions of terms was possible.

The fully prescribed component models (zero and count) for sGSL were identical:

$$f(\text{Count,Zero}) \sim \text{year} + (\text{month} + \text{home\_mgt\_areat} + \text{gear\_code} + \text{season\_duration} + \log_{10}(\text{hours}+.5)\ )^2$$

The sGSL data were also fit with logistic links for the count and zero models. The component models were simplified to:

$$f(\text{Count}) \sim \text{year} + \log_{10}(\text{hours}+.5)^2 + \text{month} + (\text{home\_mgt\_area} + \text{gear\_code} + \log_{10}(\text{hours}+.5)\ )^2 - \text{homeport}: \log_{10}(\text{hours}+.5)$$

$$f(\text{Zero}) \sim \text{year} + \text{home\_mgt\_area} + \text{month} + \log_{10}(\text{hours}+.5)^2 + (\text{gear2} + + \log_{10}(\text{hours}+.5)\ )^2$$

A summary of the final models is given in **Table 5** for SWNS and **Table 6** for sGSL.

3. Model diagnostics

The residuals of both hurdle models do not show any patterns and the variances are fairly homogeneous across all explanatory variables and the fitted values (**Figure 14**, **Figure 15**). The residuals for the SWNS model are somewhat heavy tailed but the departure from normality is not severe (**Figure 16**). The normal plot for the residuals from the sGSL model also has heavier tails than expected under normality but the distribution is symmetric around zero (**Figure 17**). The heavier tails will inflate the standard errors and lead to more conservative tests for the fixed effects.

4. Model results

The index of abundance for the SWNS fishery, shown in its nominal and standardized forms (**Figure 18**), has been increasing since a low in 2000. In the 4 years from 2000 to 2003, both the standardized and nominal trend shows a rate of change in catch that is roughly 4 times that observed or estimated from 2004 to 2011. The change point corresponds to the year when the fishery introduced individual quotas. Accounting for the effect of this change in management practice was not possible. Since 2011 the catch rates have fallen to almost the 2000 value. The sGSL indices (**Figure 19**) have shown an increasing trend since 1996. The observed and estimated abundance over the past 5 to 6 years has been very high with greater fluctuations around the trend. The greatest deviation was observed in 2010 and it also had a correspondingly large confidence interval. The uncertainty associated with the estimate can be attributed to a small number of observations for this year and that they occurred over a one week period. From about 2004 to 2010 the fishing seasons became quite fragmented (i.e. multiple short duration openings) and focused (i.e. occurred in parts of some months) (**Table 2**) and this is reflected by more variability in the series with the most aberrant being 2010. In 2011 the industry introduced self-regulatory (ITQ-like) measures that caused the fishing to once again span the entire “fishing season” as it did in 2000.

5. Research recommendations

Given the changes in the management of the SWNS fishery and the impact on the abundance index, consideration should be given in the future to splitting the series or attempting to estimate the management effect. It will also be important to revisit the catch data from 1988 to 1996 to determine the amount of zero-catch trips that should be present in the data. **Figure 20** shows that during the period when the reporting of zero catch was not mandatory, most trips were successful. Edits made to the data have changed the proportions slightly since the last reporting.

In Hanke *et al*. (2012) it was shown that a significant proportion of all candidate trips for the SWNS index involved targeting of other tunas. This practice was thought to affect the allocation of effort to the Bluefin tuna portion of the trip. As there is no specific target variable recorded in the logbooks, the entire length of the fishing trip is currently used in the bluefin CPUE calculation. **Figure 20** shows the portion of all bluefin trips that also caught other tunas (bigeye, yellowfin, albacore) continues to range from 10-40%. The current methodology for both the sGSL and SWNS limits the data to months 8-10. This has been the practice in previous assessments perhaps because few fish were caught at other times. In recent years however, substantial fishing has occurred in July and November. Thus, a reanalysis using a larger time window seems warranted. A redistribution of the fishing effort has occurred in the SWNS fishery with increasingly more trips occurring outside the domain defined in the past. The suggestion that stock components are also changing their distribution requires that the domain be expanded accordingly. The effect on the nominal indices of expanding the temporal and spatial scope of the data is shown in **Figure 21** for the SWNS index. The discrepancy between count and weight based indices serves to illustrate the changing size composition of the catch under both the current and an expanded domain.

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Table 1. Reduced dataset description for the Southwest Nova Scotia bluefin tuna fishery.

Year	*Home Management Area*					*Gear*			*Month*			*Area*		
	SF	***GNB***	***GNS***	***PEI***	***PQ***	***Harp***	***R&R***	***TL***	***Aug***	***Sep***	***Oct***	***4X***	***5Y***	***5Z***
1988	118	0	0	2	0	0	0	120	43	77	0	101	0	19
1989	181	26	44	46	25	0	1	321	173	117	32	318	1	3
1990	158	22	19	25	18	0	0	242	69	128	45	237	0	5
1991	187	10	29	81	16	0	28	295	169	83	71	321	2	0
1992	201	11	34	60	13	13	5	301	85	174	60	307	12	0
1993	327	71	118	47	93	159	0	497	201	310	145	655	0	1
1994	118	45	56	58	64	72	1	268	164	174	3	325	0	16
1995	205	55	53	67	45	88	7	330	208	171	46	414	2	9
1996	94	30	33	31	50	49	25	164	187	33	18	227	0	11
1997	148	52	7	20	31	81	45	132	179	70	9	251	0	7
1998	255	66	9	41	27	114	131	153	233	148	17	392	0	6
1999	191	33	16	51	37	70	162	96	244	74	10	327	1	0
2000	222	49	94	83	45	40	354	99	189	110	194	492	0	1
2001	307	43	57	130	52	50	421	118	256	226	107	578	4	7
2002	154	114	116	54	48	26	423	37	210	273	3	484	0	2
2003	91	34	2	26	30	19	140	24	129	54	0	182	0	1
2004	98	1	1	28	11	15	67	57	79	47	13	133	0	6
2005	86	29	0	36	4	7	132	16	70	77	8	134	0	21
2006	83	6	4	10	25	7	109	12	36	83	9	123	0	5
2007	68	7	8	0	4	13	65	9	35	39	13	80	0	7
2008	81	0	11	0	0	11	72	9	25	61	6	82	0	10
2009	68	3	2	0	0	2	55	16	17	50	6	70	0	3
2010	72	8	10	0	0	6	73	11	25	55	10	85	0	5
2011	70	2	7	0	0	4	65	10	24	44	11	76	0	3
2012	79	1	10	0	0	5	79	6	39	19	32	85	0	5
2013	87	0	9	0	0	17	52	27	21	27	48	94	0	2

Table 2. Number of observations by factor for the Gulf of St. Lawrence bluefin tuna fishery. Observations are the trip level data aggregated by day within the year, homeport, gear and month factors.

Year	***Homeport***					***Gear***		***Month***			***Days Fished Category (days)***				
	NS	***PEI***	***Que***	***GNS***	***GNB***	***RR***	***TL***	***Aug***	***Sep***	***Oct***	***(0,7]***	***(7,14]***	***(14,21]***	***(21,28]***	***(28,31]***
1981	0	87	0	0	0	0	87	31	30	26	0	0	0	26	61
1982	0	57	0	0	0	0	57	31	25	1	1	0	0	25	31
1983	0	126	0	0	0	45	81	26	48	52	0	0	26	0	100
1984	62	90	15	57	59	65	218	59	109	115	6	4	37	60	176
1985	39	88	0	36	47	0	210	65	64	81	10	22	34	53	91
1986	0	113	30	20	49	30	182	97	62	53	10	23	17	79	83
1987	9	71	0	2	23	0	105	47	40	18	14	14	20	27	30
1988	4	73	0	19	36	2	130	52	48	32	14	20	19	49	30
1989	5	86	0	18	10	8	111	45	37	37	11	22	0	25	61
1990	2	118	0	13	12	45	100	59	55	31	15	12	0	68	50
1991	6	92	0	33	7	31	107	42	37	59	17	0	29	28	64
1992	5	109	1	44	3	53	109	27	84	51	9	17	53	0	83
1993	0	160	0	79	42	114	167	62	108	111	5	24	18	118	116
1994	44	134	0	105	33	122	194	108	156	52	5	33	45	117	116
1995	0	167	1	162	3	164	169	107	116	110	4	0	0	50	279
1996	0	171	23	163	47	180	224	115	151	138	4	21	45	100	234
1997	10	179	0	148	58	214	181	91	143	161	11	0	19	66	299
1998	0	157	3	121	38	191	128	92	135	92	3	38	0	100	178
1999	0	126	0	101	28	148	107	88	131	36	14	22	23	27	169
2000	0	147	18	144	48	234	123	116	137	104	12	11	17	155	162
2001	0	134	34	110	40	216	102	131	102	85	7	36	88	126	61
2002	0	99	30	67	54	195	55	144	106	0	0	12	18	122	98
2003	0	73	31	37	37	144	34	146	32	0	19	13	0	25	121
2004	1	40	55	48	23	146	21	97	57	13	8	12	77	70	0
2005	0	64	35	55	45	154	45	98	92	9	14	24	44	81	36
2006	0	79	49	41	48	176	41	118	85	14	14	0	100	20	83
2007	10	23	44	15	10	85	17	42	21	39	26	50	0	26	0
2008	21	41	52	35	29	152	26	49	36	93	12	69	41	56	0
2009	14	23	26	20	2	73	12	36	22	27	33	30	0	22	0
2010	9	5	5	3	0	20	2	5	10	7	22	0	0	0	0
2011	30	88	11	58	31	200	18	58	83	77	11	55	62	90	0
2012	28	67	34	55	29	192	21	49	93	71	15	61	46	91	0
2013	18	77	26	40	33	168	26	29	104	61	5	65	16	65	43

Table 3. Dataset description, nominal and standardized CPUE series from the 2013 model for the Southwest Nova Scotia bluefin tuna fishery (rod and reel, tended line and harpoon), based on catch and effort data from commercial logbooks for August through October (1988-2013).

Year	***Days with Catch***			***Totals***		***Catch***		***95% CI***	
	Fail	***Succeed***	***p***	***Fish***	***Hours***	***Nominal***	***Standard***	***L***	***U***
1988	0	120	1.00	763	1232.2	61.92	13.86	9.95	19.02
1989	4	318	0.99	1737	5151.7	33.72	13.03	9.29	17.77
1990	4	238	0.98	1266	4203.0	30.12	12.32	8.99	16.82
1991	59	264	0.82	1111	5193.0	21.39	9.51	6.86	13.06
1992	3	316	0.99	1244	5514.1	22.56	9.41	6.59	12.76
1993	258	398	0.61	1064	13327.7	7.98	6.09	4.36	8.38
1994	5	336	0.99	987	6180.0	15.97	7.28	5.23	9.86
1995	0	425	1.00	1262	9629.2	13.11	7.04	4.99	9.67
1996	7	231	0.97	600	7410.2	8.1	5.56	4.04	7.6
1997	38	220	0.85	485	7013.4	6.92	4.48	3.29	6.03
1998	110	288	0.72	1002	9752.5	10.27	7.95	5.81	10.59
1999	52	276	0.84	1155	6237.1	18.52	10.82	7.68	14.8
2000	271	222	0.45	473	8516.1	5.55	4.66	3.42	6.31
2001	270	319	0.54	1218	10583.3	11.51	9.37	6.74	12.93
2002	234	252	0.52	1140	9013.9	12.65	11.49	8.19	15.54
2003	8	175	0.96	1121	6006.6	18.66	15.9	11.41	21.57
2004	11	128	0.92	531	6061.0	8.76	9.15	6.58	12.58
2005	38	117	0.75	546	5654.0	9.66	10.55	7.61	14.22
2006	2	126	0.98	633	5454.0	11.61	11.66	8.38	15.86
2007	8	79	0.91	320	3895.0	8.22	9.48	6.52	12.91
2008	2	90	0.98	532	3645.5	14.59	13.65	9.75	19.1
2009	0	73	1.00	334	2308.0	14.47	10.57	7.39	14.37
2010	2	88	0.98	327	2467.5	13.25	9.18	6.27	13.06
2011	5	74	0.94	313	2341.0	13.37	10.43	7.16	14.79
2012	4	86	0.96	317	2118.0	14.97	9.66	6.65	13.59
2013	5	91	0.95	212	2153.5	9.84	5.34	3.64	7.37

Table 4. Dataset description, nominal and standardized CPUE series for the Southern Gulf of St. Lawrence bluefin tuna fishery (tended line and rod and reel), based on catch and effort data from commercial logbooks for August through October (1981-2013).

Year	*Days with Catch*			*Totals*		*Catch*		*95% CI*	
	Fail	*Succeed*	*p*	*Fish*	*Hours*	*Nominal*	*Standard*	*L*	*U*
1981	38	49	0.56	363	12,778	2.84	1.32	0.99	1.74
1982	20	37	0.65	343	23,405	1.47	0.6	0.29	1.06
1983	34	92	0.73	566	29,167	1.94	1.54	1.25	1.85
1984	184	99	0.35	233	15,106	1.54	0.85	0.69	1.01
1985	162	48	0.23	122	22,824	0.53	0.21	0.13	0.31
1986	185	27	0.13	37	9,383	0.39	0.24	0.16	0.35
1987	96	9	0.09	10	2,145	0.47	0.32	0.15	0.53
1988	114	18	0.14	27	3,770	0.72	0.53	0.28	0.8
1989	96	23	0.19	27	3,130	0.86	0.65	0.38	1.01
1990	128	17	0.12	26	7,778	0.33	0.19	0.1	0.3
1991	113	25	0.18	31	3,187	0.97	0.65	0.42	0.93
1992	101	61	0.38	119	5,731	2.08	1.45	1.07	2.03
1993	200	81	0.29	185	10,786	1.72	0.9	0.71	1.13
1994	246	70	0.22	125	24,653	0.51	0.25	0.18	0.31
1995	183	150	0.45	370	28,486	1.3	0.72	0.6	0.85
1996	298	106	0.26	231	72,122	0.32	0.08	0.05	0.11
1997	284	111	0.28	221	56,831	0.39	0.13	0.09	0.17
1998	219	100	0.31	250	36,479	0.69	0.24	0.18	0.31
1999	159	96	0.38	385	35,396	1.09	0.42	0.32	0.52
2000	229	128	0.36	553	62,706	0.88	0.32	0.24	0.4
2001	210	108	0.34	377	52,165	0.72	0.29	0.21	0.38
2002	152	98	0.39	562	46,419	1.21	0.45	0.35	0.56
2003	84	94	0.53	488	37,366	1.31	0.83	0.68	0.99
2004	89	78	0.47	664	32,966	2.01	1.08	0.85	1.29
2005	83	116	0.58	775	47,463	1.63	1.04	0.87	1.22
2006	100	117	0.54	941	45,852	2.05	1.14	0.96	1.34
2007	33	69	0.68	576	15,066	3.82	2.28	1.79	2.99
2008	72	106	0.60	689	21,081	3.27	1.74	1.44	2.11
2009	29	56	0.66	767	14,815	5.18	2.56	1.92	3.35
2010	1	21	0.95	585	3,810	15.35	9.31	6.73	12.76
2011	61	157	0.72	625	5,747	10.87	3.7	3.13	4.49
2012	28	185	0.87	778	4,311	18.04	5.62	4.65	6.84
2013	24	170	0.88	724	4,868	14.87	4.81	3.97	5.69

Table 5. A summary of the final SWNS model (restricted).

Pearson residuals:

Min	1Q	Median	3Q	Max
-2.0115	-0.6964	-0.2366	0.5137	10.3709

Count model coefficients (truncated negbin with log link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	0.89301	0.15088	5.919	3.24E-09	***
year1989	-0.06044	0.06205	-0.974	0.330009	
year1990	-0.11491	0.06474	-1.775	0.075901	.
year1991	-0.38136	0.06681	-5.708	1.14E-08	***
year1992	-0.38667	0.0653	-5.921	3.20E-09	***
year1993	-0.83559	0.06994	-11.947	<2.00E-16	***
year1994	-0.65514	0.07051	-9.292	<2.00E-16	***
year1995	-0.68806	0.06723	-10.234	<2.00E-16	***
year1996	-0.93542	0.0799	-11.708	<2.00E-16	***
year1997	-1.16868	0.08563	-13.648	<2.00E-16	***
year1998	-0.55722	0.07038	-7.917	2.44E-15	***
year1999	-0.24512	0.06989	-3.507	0.000453	***
year2000	-1.11889	0.08731	-12.814	<2.00E-16	***
year2001	-0.3862	0.06895	-5.601	2.13E-08	***
year2002	-0.18045	0.07248	-2.49	0.012785	*
year2003	0.14151	0.07404	1.911	0.055986	.
year2004	-0.41283	0.08196	-5.037	4.73E-07	***
year2005	-0.26888	0.08432	-3.189	0.001428	**
year2006	-0.1686	0.08287	-2.034	0.041902	*
year2007	-0.38169	0.0967	-3.947	7.91E-05	***
year2008	-0.01193	0.0864	-0.138	0.890164	
year2009	-0.26779	0.09429	-2.84	0.004512	**
year2010	-0.41367	0.09517	-4.347	1.38E-05	***
year2011	-0.28366	0.09651	-2.939	0.003292	**
year2012	-0.35021	0.09744	-3.594	0.000326	***
year2013	-0.98227	0.11351	-8.654	<2.00E-16	***
month2Oct	-0.02435	0.10594	-0.23	0.818208	
month2Sept	-0.87537	0.29926	-2.925	0.003444	**
home_mgt_areaGNS	-0.1424	0.14684	-0.97	0.332165	
home_mgt_areaPEI	0.15585	0.131	1.19	0.234171	
home_mgt_areaPQ	0.11518	0.13314	0.865	0.386988	
home_mgt_areaSF	0.30382	0.11303	2.688	0.007187	**
gear_codeRR	0.04115	0.11454	0.359	0.71942	
gear_codeTL	0.64014	0.08701	7.357	1.87E-13	***
loghours	0.27887	0.10243	2.723	0.006475	**
I(loghours^2)	0.10321	0.02544	4.057	4.96E-05	***
month2Oct:gear_codeRR	-0.10573	0.07844	-1.348	0.177686	
month2Sept:gear_codeRR	-0.34113	0.18209	-1.873	0.061012	.

month2Oct:gear_codeTL	-0.14839	0.07315	-2.029	0.04249	*
month2Sept:gear_codeTL	-0.12281	0.17425	-0.705	0.480962	
month2Oct:home_mgt_areaGNS	0.15524	0.10559	1.47	0.141511	
month2Sept:home_mgt_areaGNS	0.68925	0.29724	2.319	0.020406	*
month2Oct:home_mgt_areaPEI	-0.2062	0.09738	-2.117	0.034221	*
month2Sept:home_mgt_areaPEI	0.58852	0.30408	1.935	0.052943	.
month2Oct:home_mgt_areaPQ	0.02689	0.09555	0.281	0.778412	
month2Sept:home_mgt_areaPQ	0.23412	0.3508	0.667	0.504527	
month2Oct:home_mgt_areaSF	0.10741	0.07576	1.418	0.156229	
month2Sept:home_mgt_areaSF	0.90734	0.24952	3.636	0.000277	***
month2Oct:loghours	0.02049	0.03477	0.589	0.555726	
month2Sept:loghours	0.03295	0.05022	0.656	0.511745	
home_mgt_areaGNS:loghours	-0.07658	0.10466	-0.732	0.464309	
home_mgt_areaPEI:loghours	-0.14096	0.09149	-1.541	0.123383	
home_mgt_areaPQ:loghours	-0.09339	0.09302	-1.004	0.315373	
home_mgt_areaSF:loghours	-0.16734	0.07843	-2.134	0.032869	*
gear_codeRR:loghours	0.1077	0.07664	1.405	0.159976	
gear_codeTL:loghours	-0.22288	0.05995	-3.718	0.000201	***
Log(theta)	2.09267	0.07738	27.044	<2.00E-16	***

Zero hurdle model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	17.625	960.4355	0.018	0.98536	
year1989	-14.0716	960.4356	-0.015	0.98831	
year1990	-14.5258	960.4356	-0.015	0.98793	
year1991	-16.9995	960.4354	-0.018	0.98588	
year1992	-13.6846	960.4356	-0.014	0.98863	
year1993	-17.8247	960.4354	-0.019	0.98519	
year1994	-14.1029	960.4355	-0.015	0.98828	
year1995	0.1409	1078.292	0	0.9999	
year1996	-15.1032	960.4355	-0.016	0.98745	
year1997	-16.8074	960.4354	-0.017	0.98604	
year1998	-17.4665	960.4354	-0.018	0.98549	
year1999	-16.4506	960.4354	-0.017	0.98633	
year2000	-18.1744	960.4354	-0.019	0.9849	
year2001	-17.7796	960.4354	-0.019	0.98523	
year2002	-17.7883	960.4354	-0.019	0.98522	
year2003	-15.4214	960.4355	-0.016	0.98719	
year2004	-16.6823	960.4355	-0.017	0.98614	
year2005	-17.5836	960.4355	-0.018	0.98539	
year2006	-14.5972	960.4357	-0.015	0.98787	
year2007	-16.2216	960.4355	-0.017	0.98652	
year2008	-14.6748	960.4357	-0.015	0.98781	
year2009	0.1077	1506.349	0	0.99994	

year2010	-14.1064	960.4357	-0.015	0.98828	
year2011	-15.41	960.4355	-0.016	0.9872	
year2012	-14.7732	960.4356	-0.015	0.98773	
year2013	-14.6743	960.4356	-0.015	0.98781	
month2Oct	-0.3959	0.3605	-1.098	0.27206	
month2Sept	-0.8186	0.6133	-1.335	0.18195	
home_mgt_areaGNS	-1.1532	0.4451	-2.591	0.00957	**
home_mgt_areaPEI	-0.3644	0.4348	-0.838	0.40207	
home_mgt_areaPQ	0.6068	0.4959	1.224	0.22109	
home_mgt_areaSF	-0.748	0.3847	-1.944	0.05185	.
gear_codeRR	-0.6136	0.3054	-2.01	0.04448	*
gear_codeTL	0.8358	0.2715	3.078	0.00208	**
loghours	-0.9756	0.3635	-2.684	0.00728	**
I(loghours^2)	1.1223	0.1158	9.693	<2.00E-16	***
month2Oct:gear_codeRR	-0.1084	0.2684	-0.404	0.68623	
month2Sept:gear_codeRR	1.2244	0.4765	2.57	0.01018	*
month2Oct:gear_codeTL	0.1541	0.2586	0.596	0.55136	
month2Sept:gear_codeTL	0.7323	0.4726	1.55	0.12125	
month2Oct:home_mgt_areaGNS	-0.1134	0.3312	-0.342	0.73202	
month2Sept:home_mgt_areaGNS	0.2447	0.4745	0.516	0.60598	
month2Oct:home_mgt_areaPEI	-0.6741	0.3476	-1.939	0.05249	.
month2Sept:home_mgt_areaPEI	-1.0522	0.5292	-1.988	0.04676	*
month2Oct:home_mgt_areaPQ	-0.4212	0.3886	-1.084	0.27832	
month2Sept:home_mgt_areaPQ	-1.0576	0.5564	-1.901	0.05734	.
month2Oct:home_mgt_areaSF	0.8434	0.2763	3.052	0.00227	**
month2Sept:home_mgt_areaSF	0.6225	0.4053	1.536	0.12462	
month2Oct:loghours	-0.2259	0.1637	-1.38	0.16753	
month2Sept:loghours	-1.008	0.2106	-4.786	1.70E-06	***
home_mgt_areaGNS:loghours	0.5267	0.368	1.431	0.15233	
home_mgt_areaPEI:loghours	1.0257	0.3354	3.058	0.00223	**
home_mgt_areaPQ:loghours	0.2496	0.3722	0.671	0.5025	
home_mgt_areaSF:loghours	0.5234	0.2918	1.793	0.07294	.
gear_codeRR:loghours	0.6465	0.2301	2.81	0.00496	**
gear_codeTL:loghours	-0.1561	0.2083	-0.749	0.45363	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta: count = 8.1065

Number of iterations in BFGS optimization: 70

Log-likelihood: -1.29e+04 on 113 Df

Table 6. A summary of the final sGSL model.

Call:
hurdle(formula = f17, data = b, dist = "negbin", zero.dist = "binomial", link = "logit")

Pearson residuals:

Min	1Q	Median	3Q	Max
-1.55232	-0.50365	-0.26431	0.06694	11.31676

Count model coefficients (truncated negbin with log link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-3.60511	0.2684	-13.432	< 2e-16	***
yr1982	-0.61562	0.15126	-4.07	4.70E-05	***
yr1983	-0.62028	0.13435	-4.617	3.89E-06	***
yr1984	-0.85323	0.15108	-5.648	1.63E-08	***
yr1985	-1.64737	0.17437	-9.448	< 2e-16	***
yr1986	-1.99756	0.34795	-5.741	9.41E-09	***
yr1987	-1.97226	1.02262	-1.929	0.053777	.
yr1988	-0.9339	0.37629	-2.482	0.013071	*
yr1989	-1.24279	0.53126	-2.339	0.019319	*
yr1990	-1.65563	0.37049	-4.469	7.87E-06	***
yr1991	-1.11043	0.44303	-2.506	0.012196	*
yr1992	-0.26195	0.19413	-1.349	0.17722	
yr1993	-0.63552	0.16013	-3.969	7.22E-05	***
yr1994	-2.03133	0.18669	-10.881	< 2e-16	***
yr1995	-0.89957	0.13748	-6.543	6.02E-11	***
yr1996	-2.32311	0.15234	-15.249	< 2e-16	***
yr1997	-2.4299	0.16772	-14.488	< 2e-16	***
yr1998	-1.76783	0.15867	-11.142	< 2e-16	***
yr1999	-1.38071	0.15337	-9.002	< 2e-16	***
yr2000	-1.61003	0.15064	-10.688	< 2e-16	***
yr2001	-1.74436	0.15595	-11.185	< 2e-16	***
yr2002	-1.254	0.15223	-8.237	< 2e-16	***
yr2003	-1.10301	0.15819	-6.973	3.11E-12	***
yr2004	-0.57195	0.16248	-3.52	0.000431	***
yr2005	-0.91774	0.15465	-5.934	2.95E-09	***
yr2006	-0.62411	0.1513	-4.125	3.71E-05	***
yr2007	0.07028	0.16964	0.414	0.678653	
yr2008	-0.17148	0.15877	-1.08	0.280119	
yr2009	0.3048	0.16534	1.843	0.065265	.
yr2010	1.3853	0.21202	6.534	6.42E-11	***
yr2011	0.50356	0.14882	3.384	0.000715	***
yr2012	0.86212	0.15017	5.741	9.41E-09	***
yr2013	0.69061	0.14987	4.608	4.07E-06	***
I(hrsfish2.lg^2)	-0.14253	0.04763	-2.993	0.002765	**
month39	0.2838	0.04548	6.24	4.37E-10	***

month310	0.31694	0.05696	5.564	2.63E-08	***
homeport2	0.58071	0.16402	3.54	0.0004	***
homeport3	0.25338	0.16874	1.502	0.133202	
homeport5	0.33693	0.16068	2.097	0.036009	*
homeport6	0.53398	0.1659	3.219	0.001287	**
gear236	-1.68825	0.56763	-2.974	0.002938	**
hrsfish2.lg	2.63316	0.20706	12.717	< 2e-16	***
homeport2:gear236	-0.17793	0.51576	-0.345	0.730103	
homeport3:gear236	0.51292	0.91641	0.56	0.575678	
homeport5:gear236	0.34776	0.5513	0.631	0.528176	
homeport6:gear236	1.16142	0.55911	2.077	0.037776	*
gear236:hrsfish2.lg	0.52968	0.1543	3.433	0.000597	***
Log(theta)	1.31884	0.07863	16.772	< 2e-16	***

Zero hurdle model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-1.37056	0.38255	-3.583	0.00034	***
yr1982	-0.71436	0.54506	-1.311	0.189991	
yr1983	1.70274	0.39099	4.355	1.33E-05	***
yr1984	0.13984	0.32516	0.43	0.667156	
yr1985	-1.58641	0.36663	-4.327	1.51E-05	***
yr1986	-1.31525	0.36654	-3.588	0.000333	***
yr1987	-0.90619	0.45504	-1.991	0.046429	*
yr1988	-0.64962	0.38775	-1.675	0.09386	.
yr1989	-0.11061	0.37191	-0.297	0.766152	
yr1990	-1.69227	0.3952	-4.282	1.85E-05	***
yr1991	-0.16448	0.3637	-0.452	0.651103	
yr1992	0.58763	0.33625	1.748	0.080537	.
yr1993	0.03023	0.32111	0.094	0.924998	
yr1994	-1.29337	0.32977	-3.922	8.78E-05	***
yr1995	-0.14214	0.31137	-0.456	0.648039	
yr1996	-2.5542	0.32684	-7.815	5.50E-15	***
yr1997	-2.01874	0.32424	-6.226	4.78E-10	***
yr1998	-1.36558	0.32623	-4.186	2.84E-05	***
yr1999	-0.73273	0.33616	-2.18	0.029278	*
yr2000	-1.04641	0.33203	-3.152	0.001624	**
yr2001	-1.14383	0.34308	-3.334	0.000856	***
yr2002	-0.69493	0.35495	-1.958	0.050252	.
yr2003	0.33242	0.35297	0.942	0.346301	
yr2004	0.36719	0.35692	1.029	0.30358	
yr2005	0.72475	0.3469	2.089	0.03669	*
yr2006	0.57368	0.33946	1.69	0.091033	.
yr2007	1.42586	0.38045	3.748	0.000178	***
yr2008	1.00354	0.34405	2.917	0.003536	**

yr2009	1.12523	0.39903	2.82	0.004804	**
yr2010	3.68307	1.08433	3.397	0.000682	***
yr2011	2.12155	0.33561	6.321	2.59E-10	***
yr2012	3.41115	0.36327	9.39	< 2e-16	***
yr2013	3.41454	0.37213	9.176	< 2e-16	***
homeport2	-1.08165	0.17954	-6.025	1.69E-09	***
homeport3	-0.99672	0.20548	-4.851	1.23E-06	***
homeport5	-1.25385	0.18144	-6.91	4.83E-12	***
homeport6	-0.73829	0.19026	-3.88	0.000104	***
month39	0.49416	0.0828	5.968	2.41E-09	***
month310	0.46398	0.09584	4.841	1.29E-06	***
I(hrsfish2.lg^2)	1.08512	0.0809	13.413	< 2e-16	***
gear236	-0.31925	0.21178	-1.507	0.131687	
hrsfish2.lg	-0.66047	0.25272	-2.613	0.008962	**
gear236:hrsfish2.lg	-0.12832	0.1247	-1.029	0.303457	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta: count = 3.7391
Number of iterations in BFGS optimization: 57
Log-likelihood: -7333 on 91 Df

Figure 1. Historic distribution of trips in the Southwest Nova Scotia(SWNS) and Southern Gulf of St. Lawrence (sGSL) bluefin fisheries between 1981 and 2012, in 6-year intervals. Bottom panel is limited to the 2013 season. Trips falling outside of the blue area are currently excluded from the indices.

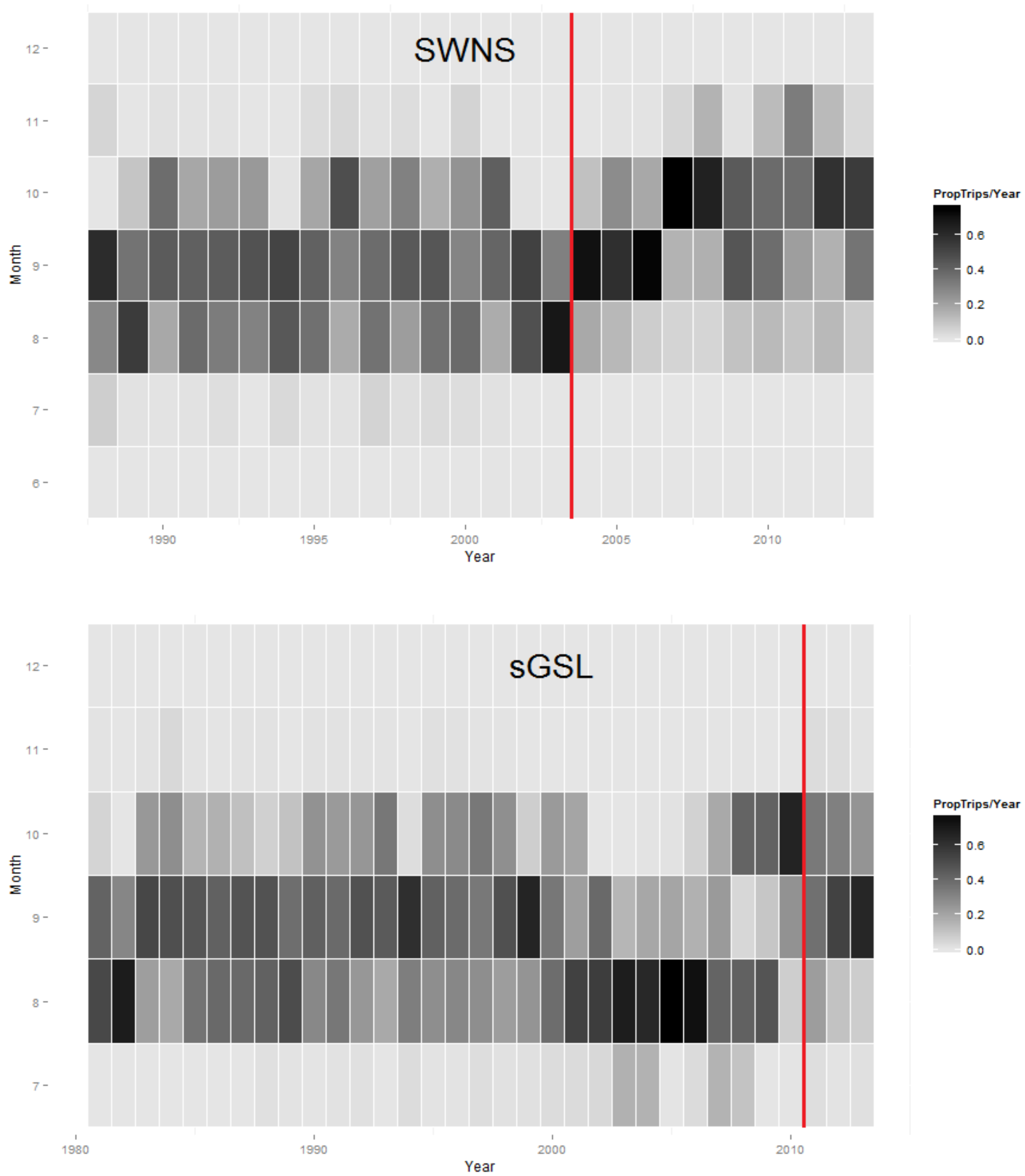


Figure 2. Season progression using proportion of trips by month within a given year in the Southwest Nova Scotia (top) and Gulf St. Lawrence (bottom) Bluefin tuna catch data. Solid line indicates switch from competitive to an ITQ-like structure in each fishery.

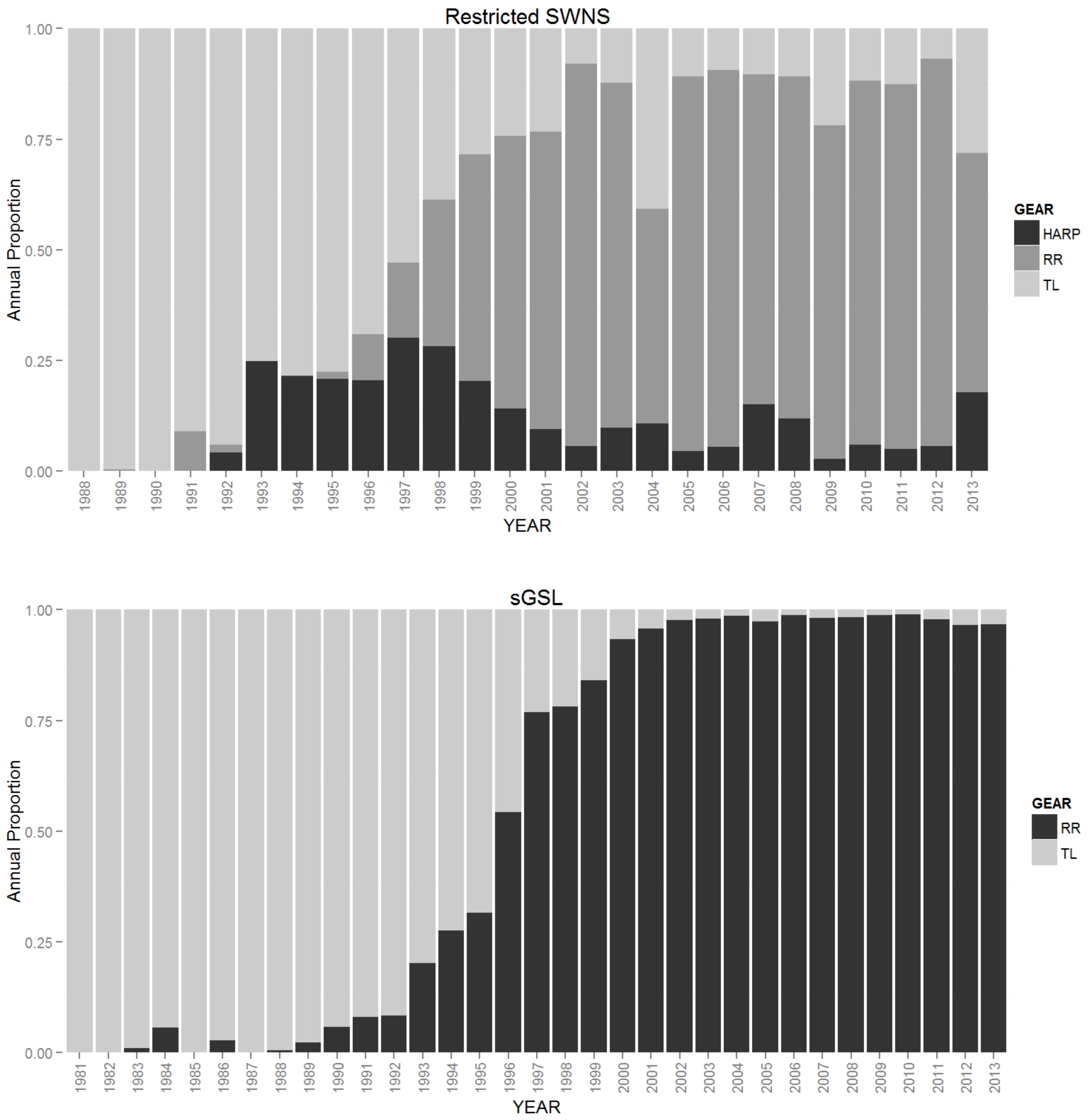


Figure 3. Relative frequency of records gears (tended line, rod and reel, harpoon) within year for the Southwest Nova Scotia (top) and Gulf St. Lawrence (bottom) bluefin tuna fisheries.

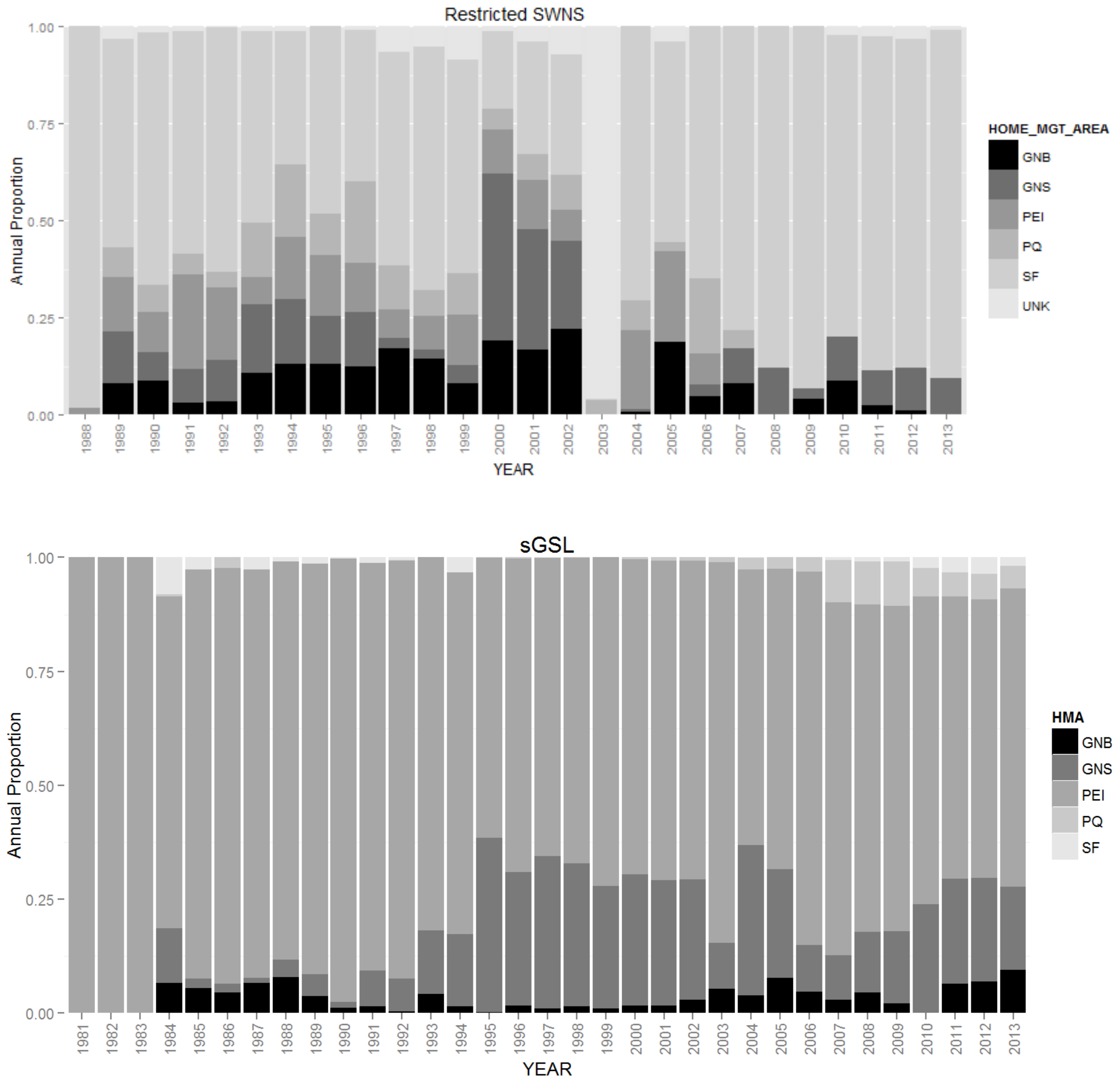


Figure 4. Relative frequency of records by year and home management areas (fleets) within year for the Southwest Nova Scotia (top) and Gulf St. Lawrence (bottom) Bluefin fisheries. The SWNS dataset has historical restrictions applied, as the majority of the area restrictions affect activity by ex-sector fleets.

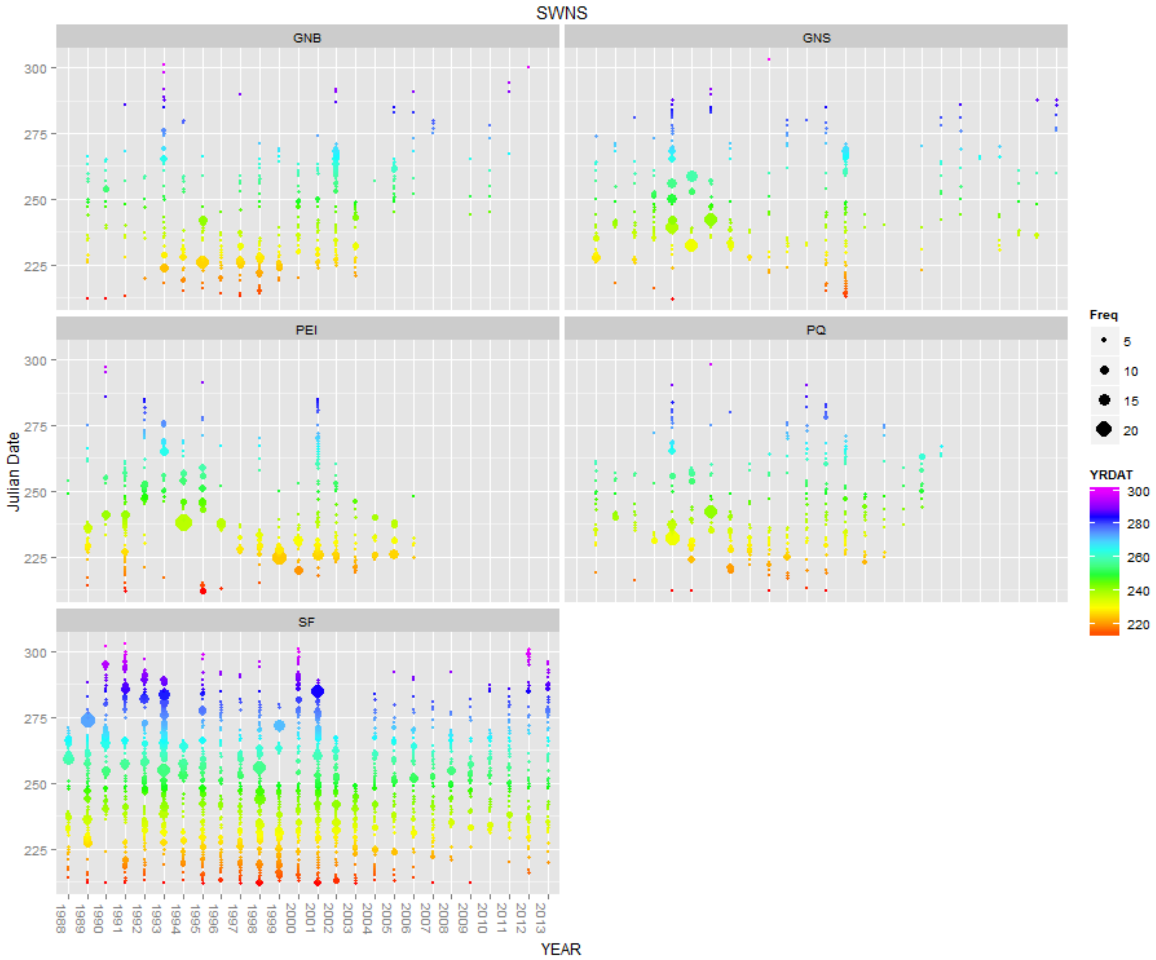


Figure 5. Frequency of trips by bluefin tuna fleets fishing in the southwest Nova Scotia fishery (1988-2013).

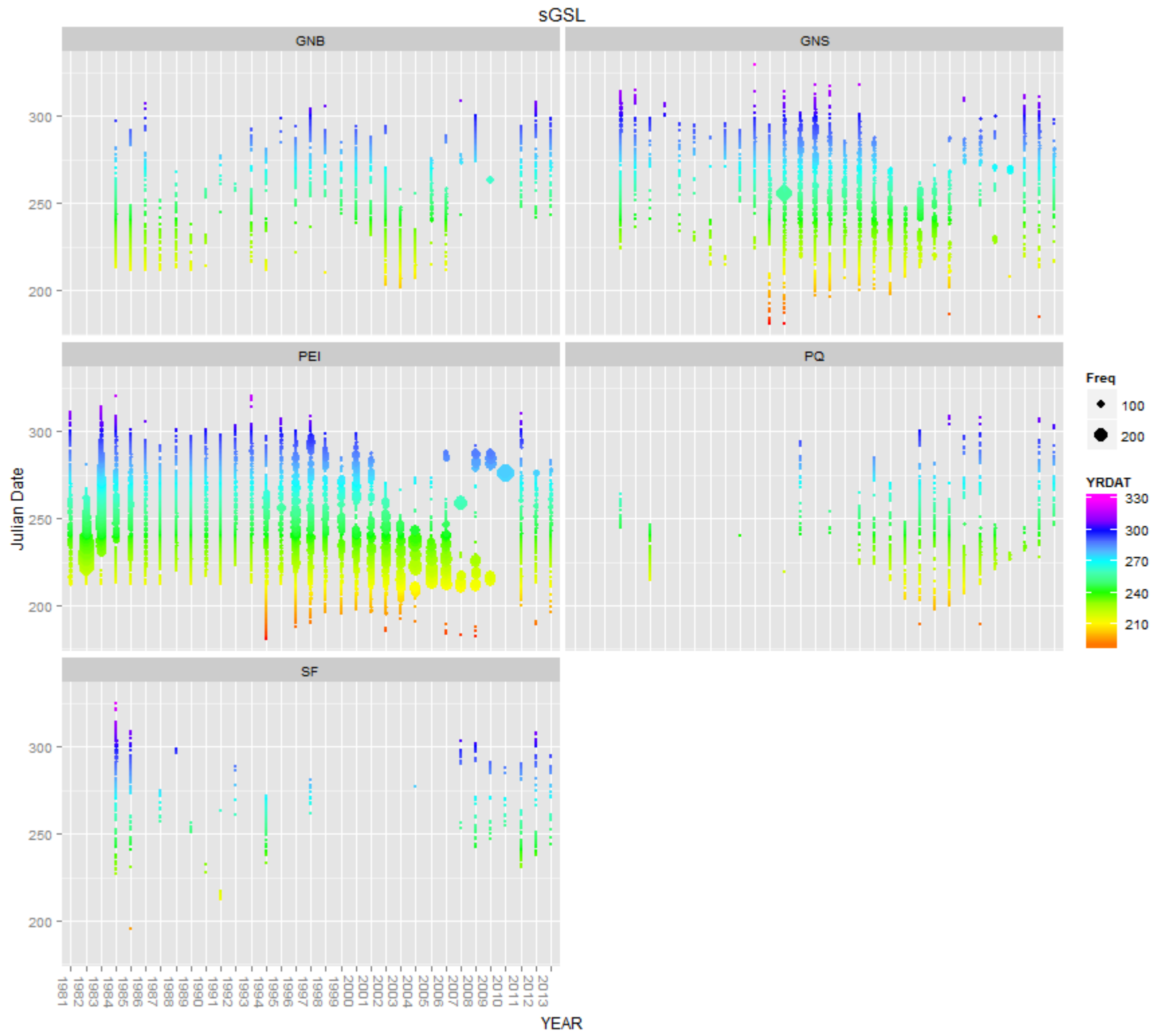


Figure 6. Frequency of trips by bluefin tuna fleets fishing in the Gulf of St. Lawrence (1981-2013).

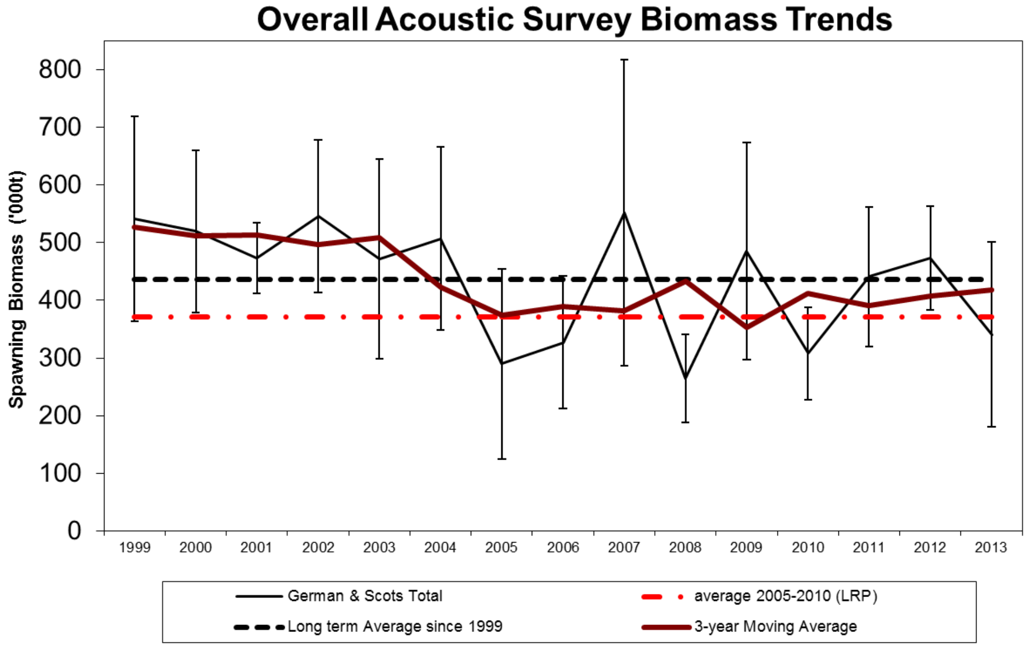


Figure 7. Relative herring spawning stock biomass index (95% SE), the calculated three-year moving average, the long-term average and the limit reference point (ave 2005-2010) for the SW Nova Scotia/Bay of Fundy herring spawning component (DFO, 2014a).

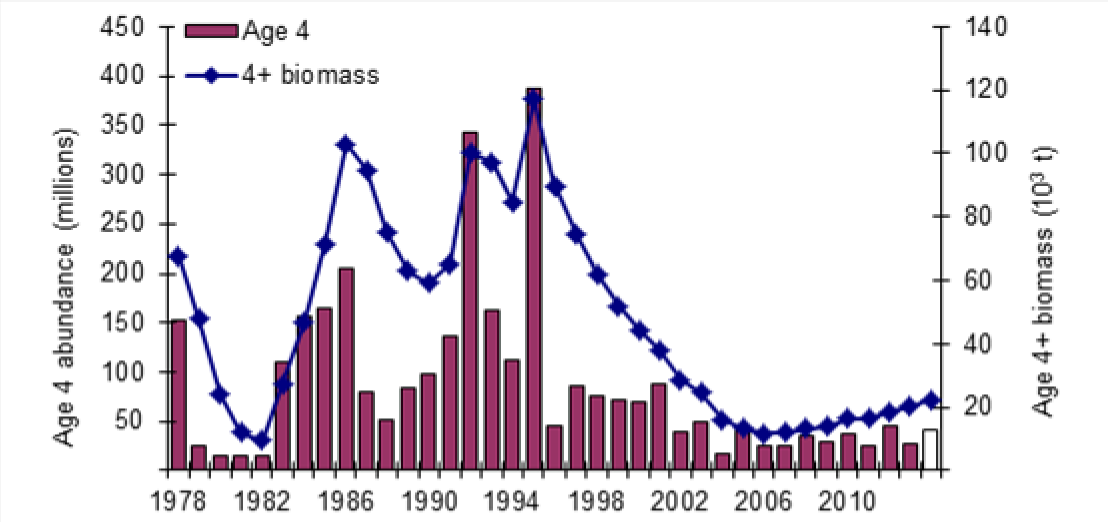


Figure 8. Start of year herring spring spawner component age 4 numbers (millions of fish) and age 4+ spawning stock biomass (103 t), 1978 to 2014. The value for age 4 abundance in 2014 is an estimate based on recruitment rate of 2009-2013 (DFO, *in press*).

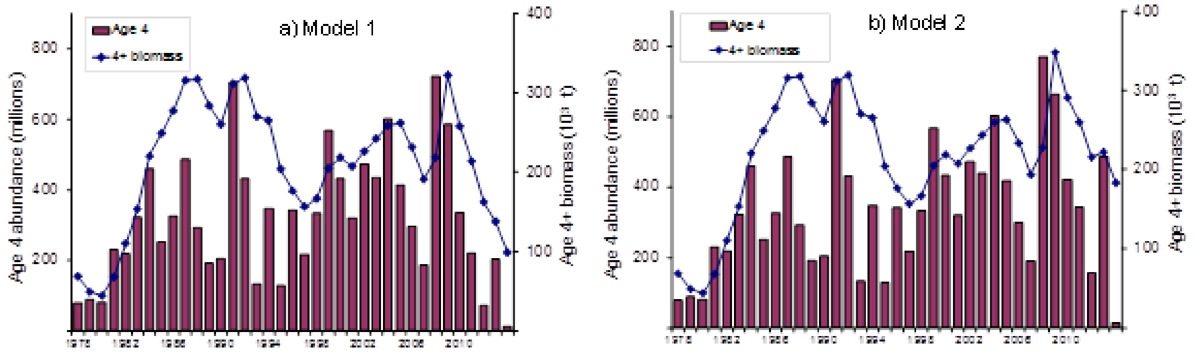


Figure 9. Herring fall spawner component age 4 numbers (millions of fish) and age 4+ biomass (103 t) from a) model 1 (left panel) and b) model 2 (right panel) (from DFO, in press).

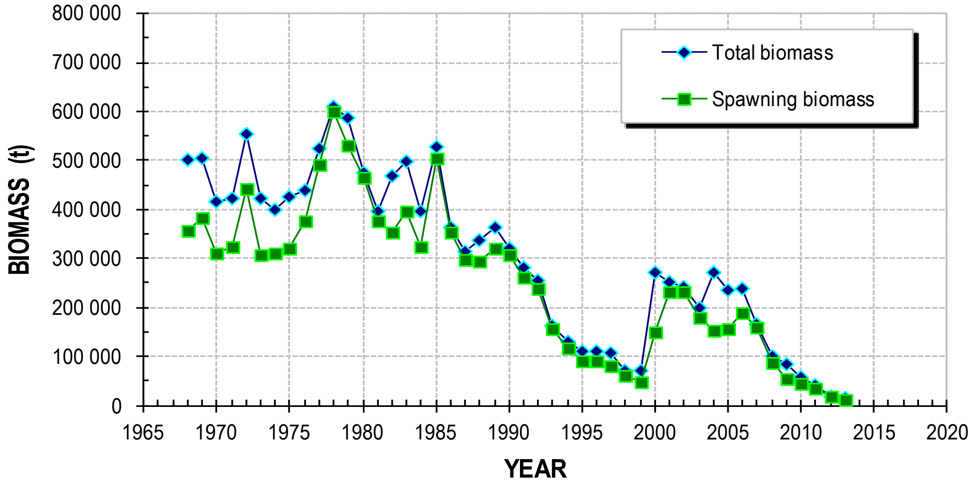


Figure 10. Total and spawning Atlantic mackerel biomasses (t) in NAFO subareas 3 and 4 for the 1968–2013 period (from DFO, 2014b).

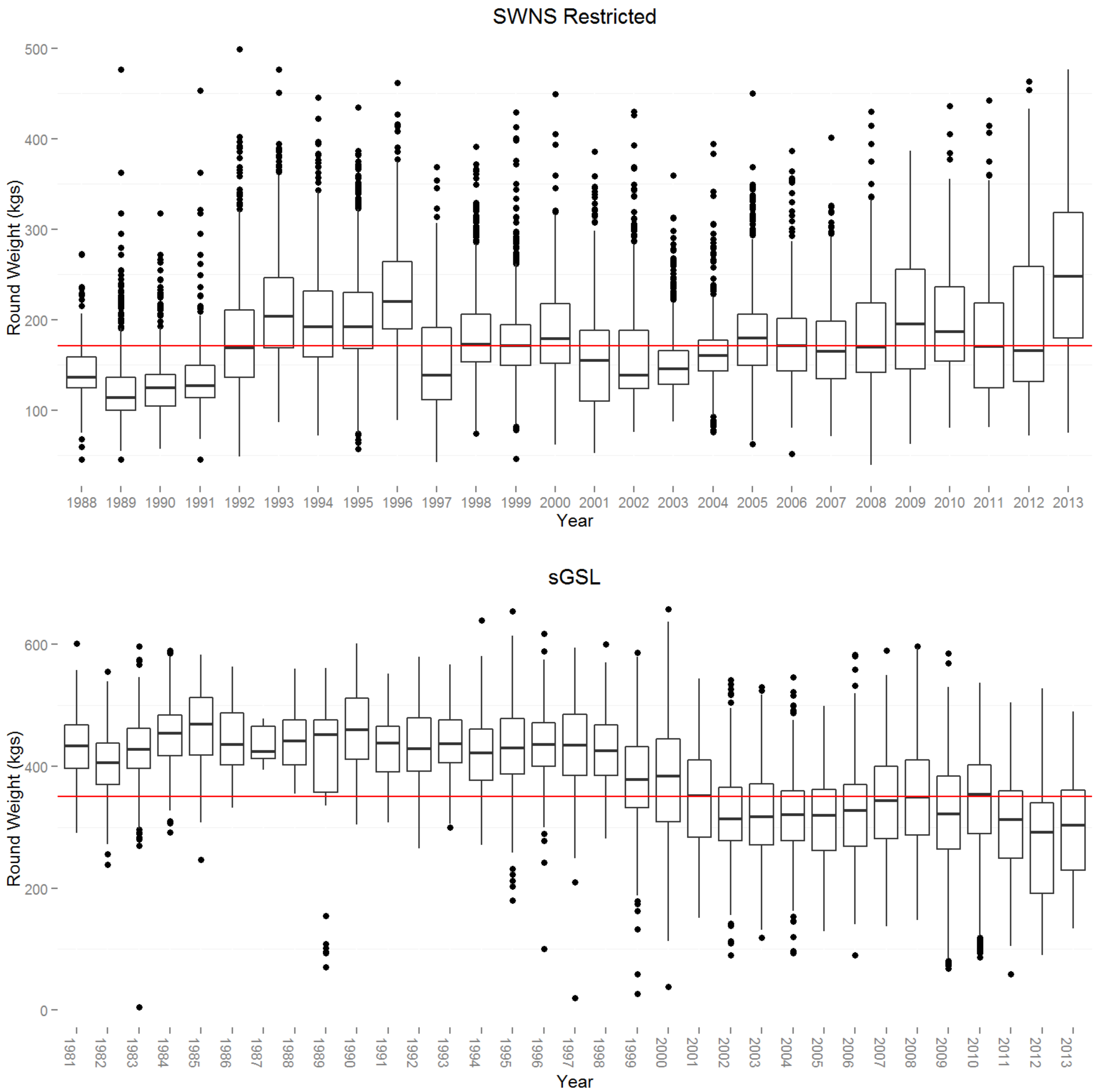


Figure 11. Round weight (kg) of recent catches made in the Southwest Nova Scotia (top) and Gulf of St. Lawrence (bottom) bluefin fisheries. Red line indicates series mean.

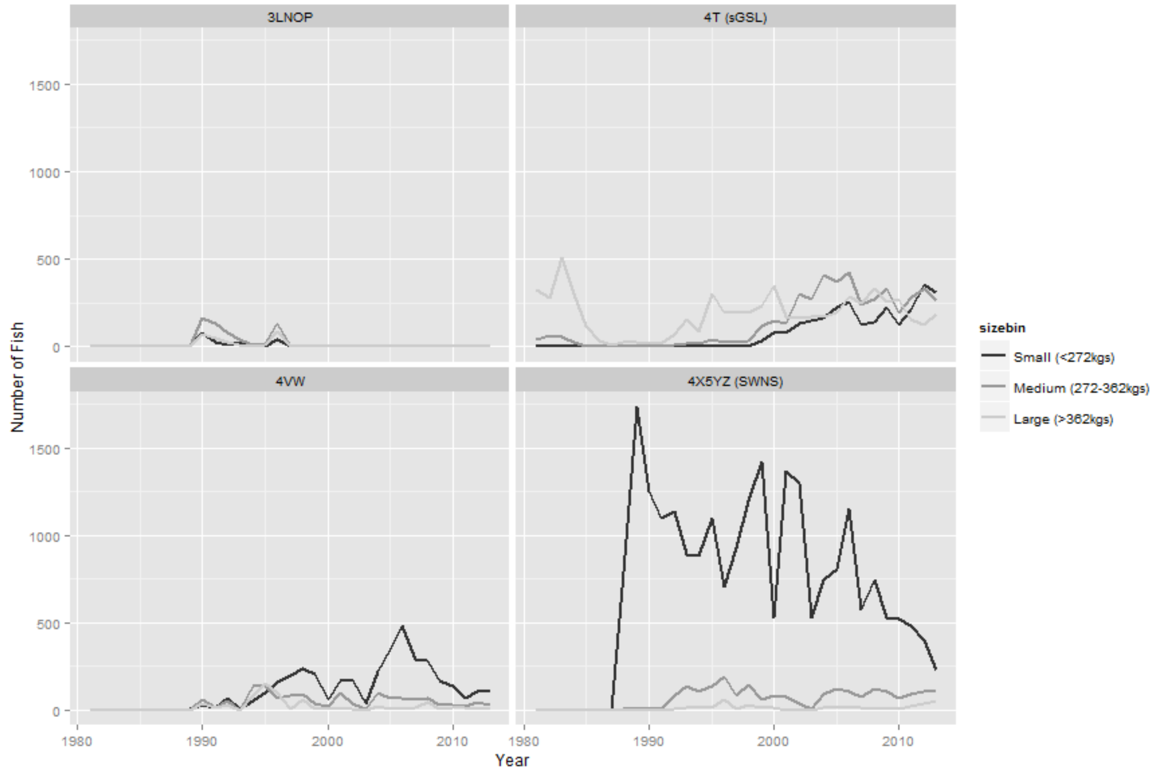


Figure 12. Annual frequency of Bluefin tuna catch by size, area and year. NAFO areas 4X5YZ encompass the SWNS fishery, while NAFO 4T represents the sGSL fishery. 3LNOP and 4VW fall outside of both fisheries.

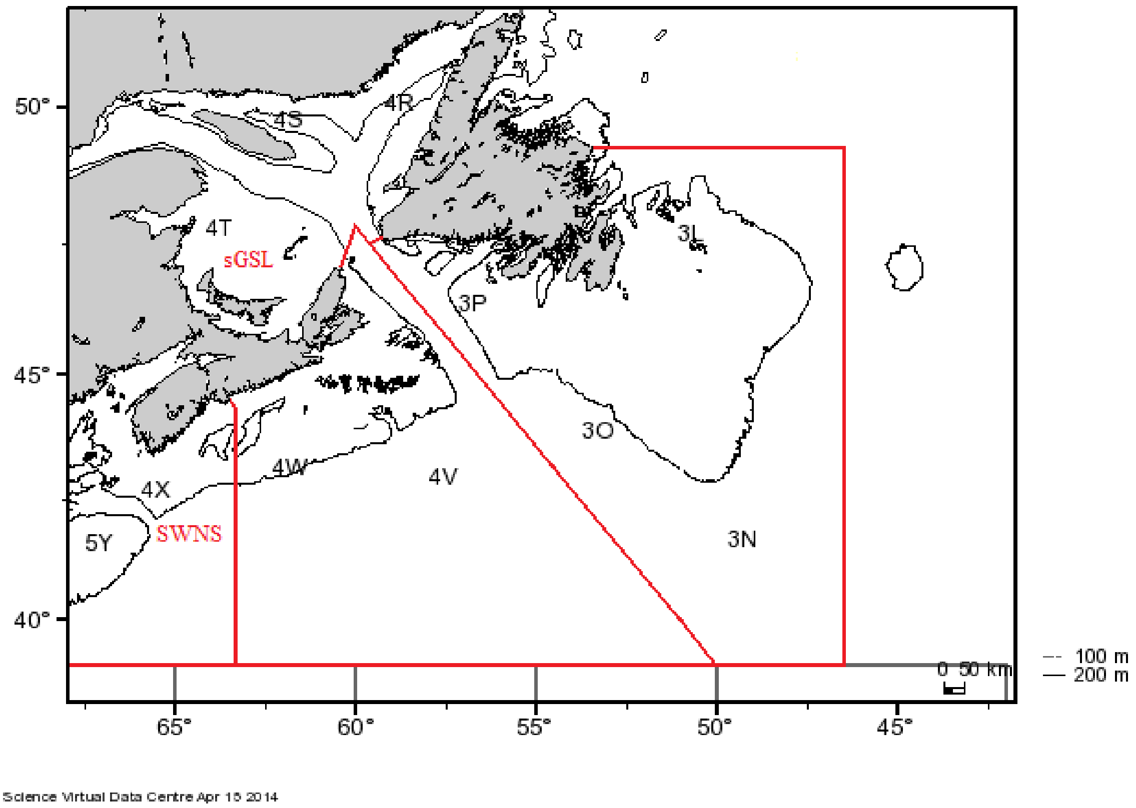


Figure 13. Map delimiting major NAFO areas groups within the Canadian EEZ.

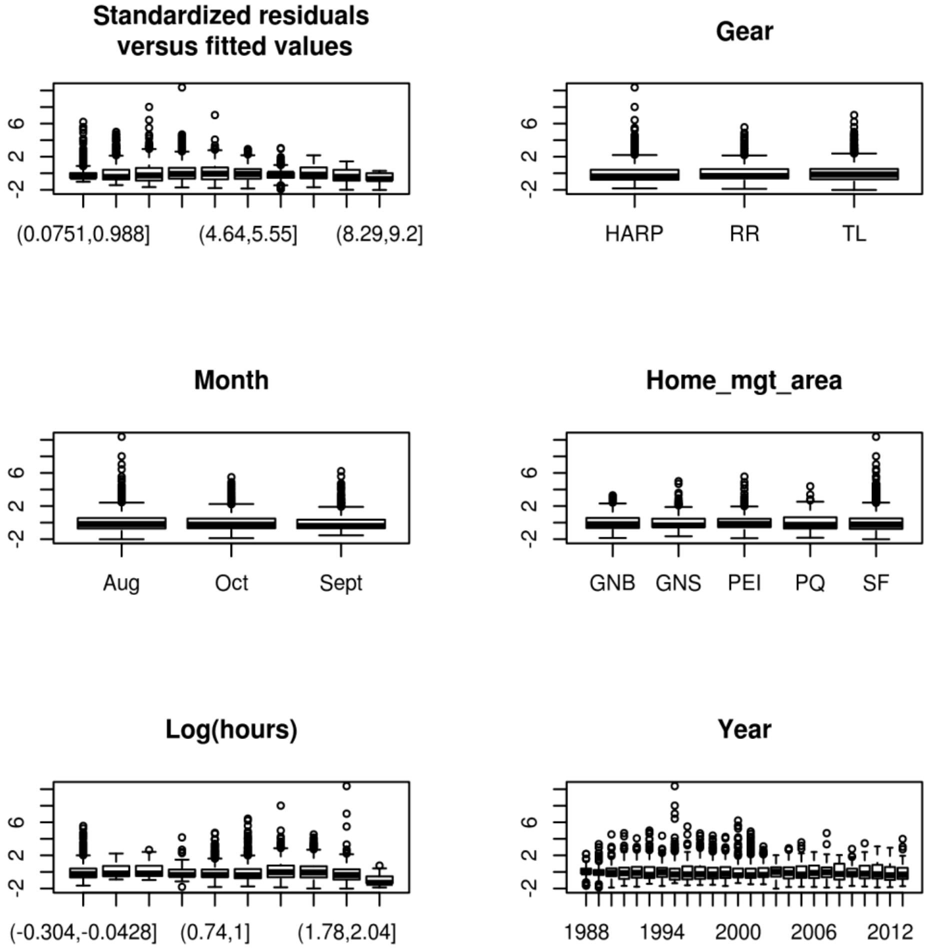


Figure 14. Plots of standardized residuals from the SWNS model to test for homogeneity of variance.

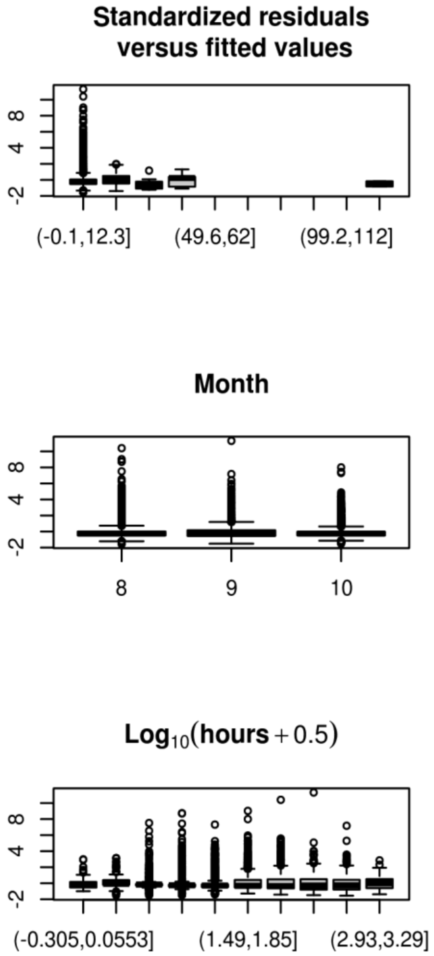


Figure 15. Plots of standardized residuals from the sGSL model to test for homogeneity of variance.

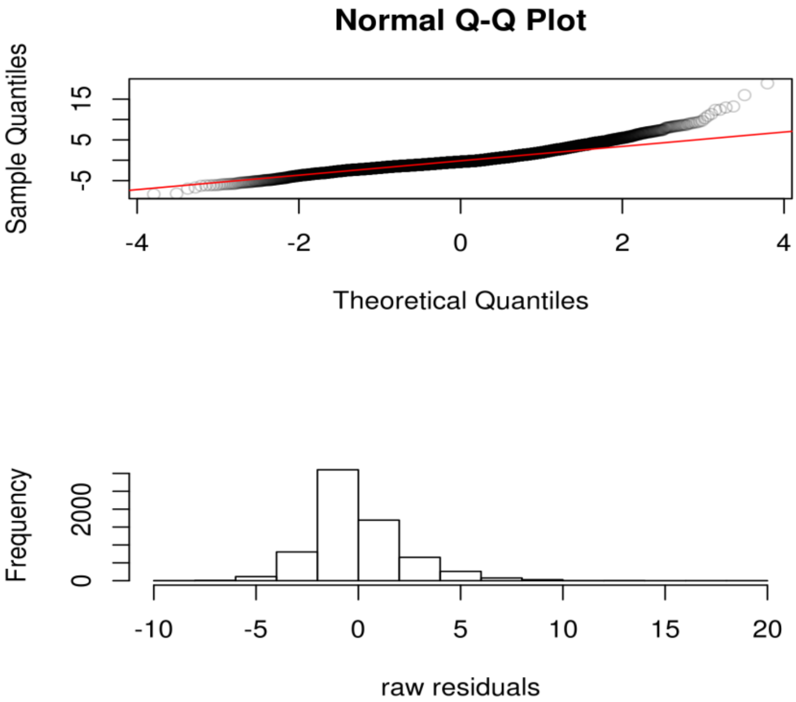


Figure 16. Raw residuals for the SWNS model (restricted).

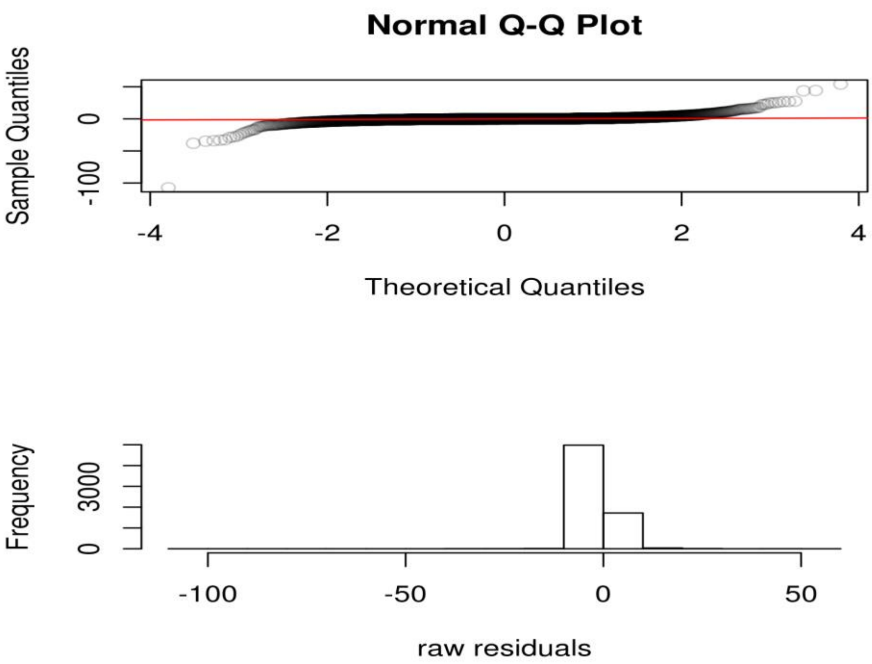


Figure 17. Raw residuals from the sGSL model.

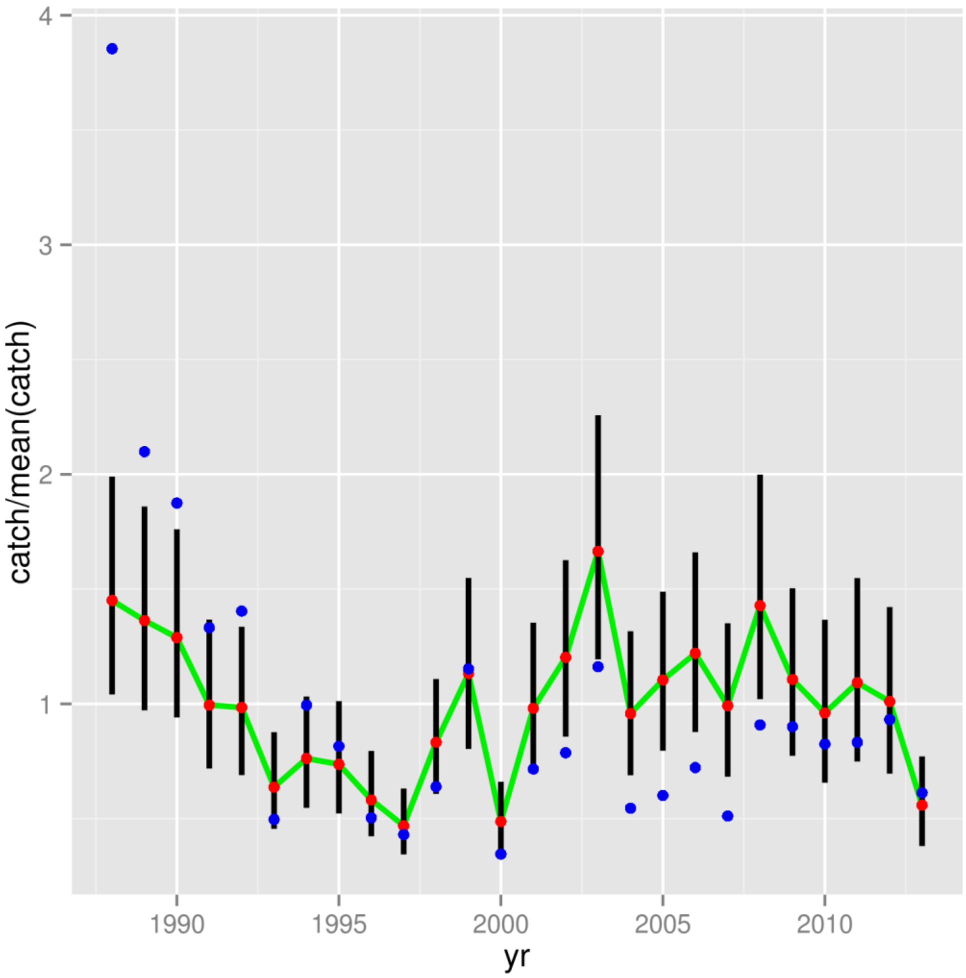


Figure 18. Standardized (green line) and nominal indices (blue points) for the SWNS bluefin tuna fishery. Line ranges represent the upper 97.5% and lower 2.5% index values from 500 bootstrap runs.

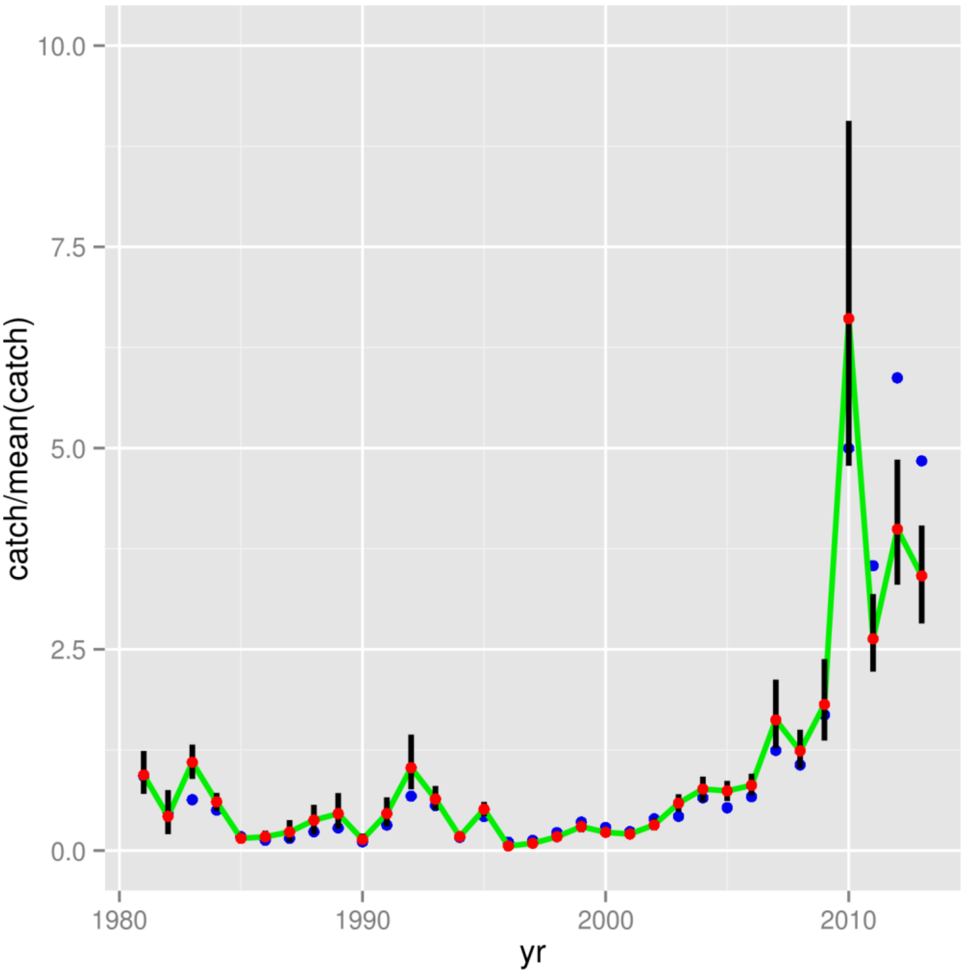
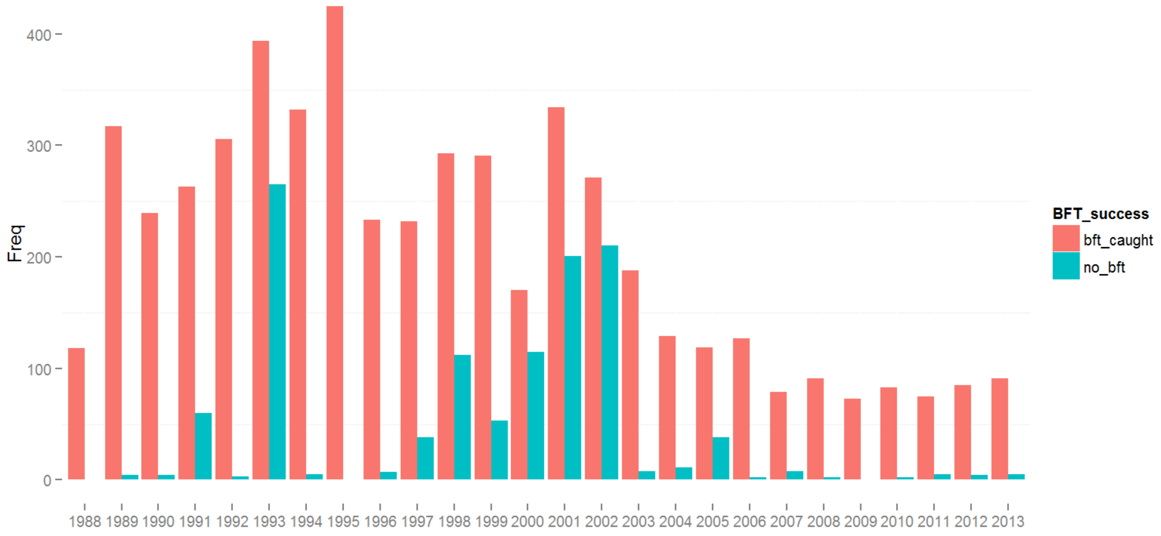


Figure 19. Standardized (green line) and nominal indices (blue points) for the sGSL bluefin tuna fishery. Line ranges represent the upper 97.5% and lower 2.5% index values from 500 bootstrap runs.



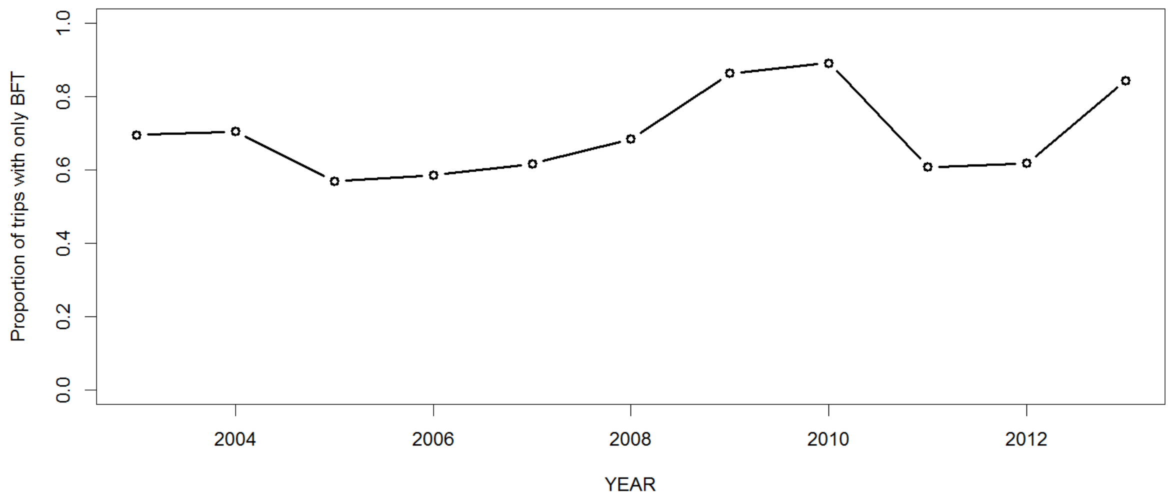


Figure 20. Annual proportion of successful and unsuccessful trips (top) in the SWNS fishery. Bottom plot shows proportion of successful Southwest Nova Scotia trips with only bluefin catches.

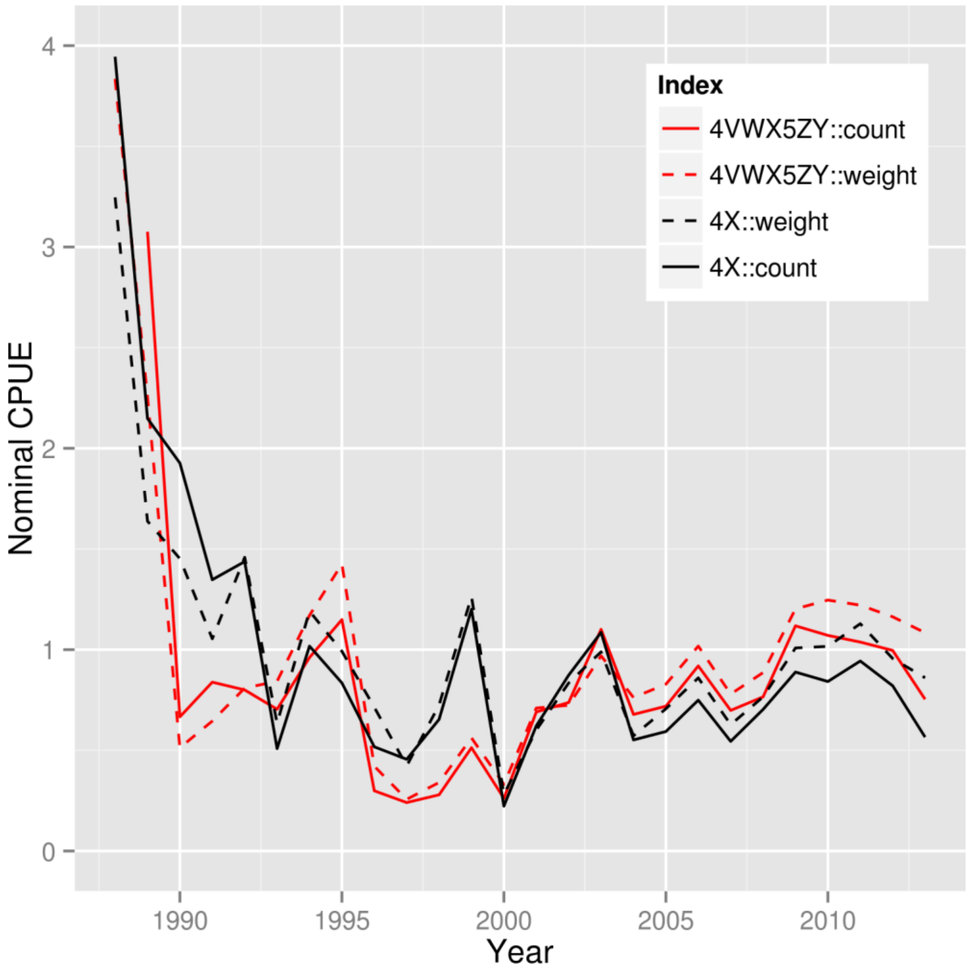


Figure 21. Nominal SWNS CPUE indices based on count (solid) and weight (dashed) of Bluefin tuna based on restricted (black) and unrestricted (red) datasets**.**