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An Examination of Loggerhead Sea Turtle (*Caretta caretta*) Encounters in the Canadian Swordfish and Tuna Longline Fishery, 2002-2008

Examen des rencontres de caouannes (*Caretta caretta*) dans la pêche canadienne de l'espadon et du thon à la palangre (2002-2008)

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TABLE OF CONTENTS

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ABSTRACT

Loggerhead sea turtles (*Caretta caretta*) were listed as threatened under the *USA Endangered Species Act* in 1978 and listed endangered on the International Union for Conservation of Nature (IUCN) Red Listing in 1996 and by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2010. Estimates of loggerhead sea turtle encounters by the Canadian swordfish and tuna longline fleet were derived from commercial landings and observer data from Maritimes and Newfoundland regions for 2002-2008.

Set-level encounter rates of the swordfish component of the Canadian fishery (2005-2007) were comparable with published estimates from the USA pelagic longline fishery for sets made in the same area and season, whereas the tuna-targeted Canadian fishery had a higher median encounter rate than did the swordfish-targeted component of the Canadian fishery.

Delta-lognormal and ratio estimation approaches, with stratifying and prorating variables such as quarter, region, commercial landings and the number of hooks per trip, were used to estimate fleet-wide loggerhead sea turtle encounters. Overall, these approaches showed the same trends when similarly stratified, notably a decrease in encounters from 2006 to 2008. However, a major difference was that the delta-lognormal approach predicted almost 50% fewer loggerhead sea turtle encounters compared to the ratio estimation approach. It was resolved that the ratio estimation approach best represented loggerhead sea turtle encounters by the longline fleet. Using that approach, it was estimated 1,200 loggerhead sea turtles (95% confidence range of 700-1,800) were caught annually in the Canadian swordfish and tuna longline fishery during the period 2002-2008.

RÉSUMÉ

La caouanne (*Caretta caretta*) a été désignée espèce menacée en vertu de la *Endangered Species Act* des États-Unis en 1978. De plus, elle figure comme espèce en voie de disparition depuis 1996 sur la Liste rouge de l’Union internationale pour la conservation de la nature (IUCN) depuis 1996 et depuis 2010 sur la liste établie par le Comité sur la situation des espèces en péril au Canada (COSEPAC). Le nombre de caouannes rencontrées par la flottille canadienne de pêche de l’espadon et du thon à la palangre a été estimé d’après les débarquements commerciaux et les données des observateurs des Régions des Maritimes et de Terre-Neuve du MPO pour 2002-2008.

Les taux de rencontre par calée dans le volet de cette pêche canadienne axé sur l’espadon (2005-2007) se comparaient aux estimations publiées de ceux de la flottille de pêche à la palangre pélagique des États-Unis pour ce qui est des calées effectuées dans la même zone et à la même saison. En revanche, dans le volet de la pêche canadienne axé sur le thon, le taux médian de rencontres était supérieur à celui de la même flottille dans la pêche de l’espadon.

On a eu recours à des modèles d'évaluation delta-lognormal et d'évaluation par quotient, avec des variables de stratification et de calcul proportionnel comme le trimestre, la région, les débarquements et le nombre d'hameçons utilisés par sortie, pour estimer les rencontres de caouannes dans l'ensemble de la flottille. Globalement, ces modèles reflétaient les mêmes tendances quand on leur appliquait la même stratification, en particulier une diminution du nombre de rencontres de 2006 à 2008. Il y avait toutefois une grande différence entre les deux modèles, le modèle delta-lognormal produisant un nombre de rencontres inférieur de près de 50 % à celui du modèle d'évaluation par quotient. Il a été décidé que c'est ce dernier modèle qui représentait le mieux le nombre de caouannes rencontrées par la flottille de palangriers. En se fondant sur ce modèle, on a estimé que 1 200 caouannes (intervalle de confiance de 95 % de l'ordre de 700 à 1 800) ont été capturées chaque année dans la pêche canadienne de l'espadon et du thon à la palangre de 2002 à 2008.

INTRODUCTION

Traditionally, the Canadian pelagic longline fleet has targeted swordfish (*Xiphias gladius*) from June through October along the edge of the continental shelf from Georges Bank to the Grand Banks of Newfoundland. The fishing effort shifted from west to east, tracking swordfish movements associated with seasonal warming trends of sea surface temperature. In the early to middle 1990s effort began to shift south and east of the continental shelf early and late in the fishing season to target albacore (*Thunnus alalunga*), bigeye (*T. obesus*) and yellowfin tunas (*T. albacares*). In the late 1990s, when swordfish quotas were low, fishing patterns began to change. The tunas, particularly bigeye tuna, garnered more attention from the fleet, and fishing effort expanded further east of Newfoundland and further south of the continental shelf. In 2002 the fleet came under Individual Transferable Quotas (ITQ) management, which allowed the fleet to target swordfish and tunas concurrently. In recent years, the longline fleet has become a multi-species fishery, targeting swordfish and tunas from May through December from Georges Bank to east of the Flemish Cap, along the edge of the continental shelf and Grand Banks of Newfoundland, and southwards. Since 2002, the percentage of tunas landed has been 18-31% compared to swordfish, with yellowfin tuna being the most prominent tuna species since 2004 (Figure 1).

The recent evolution of this fishery has raised concern over the effectiveness of the definition of targeting in studies using these data. When targeting swordfish, the fleet primarily baits with mackerel and fishes in cooler water along the edge of the continental shelf and Grand Banks of Newfoundland. When targeting tunas, the preferred bait is squid and the fleet fishes in warmer water south of the continental shelf edge and east of Newfoundland (Figure 2). Albacore and bigeye tunas are caught throughout the range of the fishery; however, the catch of yellowfin tuna is generally restricted to the western fishing area, and occurs the furthest south (Figure 3). The conventional method for classifying the target species is to use the weight of each landed species on a given trip. For example, if the landed weight of swordfish on a trip is greater than the combined weight of tunas, it is considered a swordfish-targeted trip. Paul and Neilson (2009) examined set-level data of sea surface temperature and bait type from logbook records in order to test these variables as alternatives to the established method of calculating targeting. All three variables provided generally comparable results; however, sea surface temperature and bait type did not perform better than the conventional method.

The Canadian swordfish and tuna longline fishery incidentally catches loggerhead sea turtles (*Caretta caretta*) during the course of its fishing operations. Loggerhead sea turtles were listed as threatened under the *USA Endangered Species Act* in 1978 (Conant *et al.*, 2009). They were listed as endangered on the International Union for Conservation of Nature (IUCN) Red Listing in 1996, and in 2010 they were designated endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The purpose of this report is to provide the best estimate of encounters of loggerhead sea turtle in the fishery, to make comparisons to existing published estimates and contrast the different approaches that have been used to estimate encounters. In particular, we will consider approaches used in Canada (Brazner and McMillan, 2008) and the USA (Fairfield-Walsh and Garrison, 2006; Fairfield-Walsh and Garrison, 2007; Fairfield-Walsh and Garrison, 2008 and Garrison *et al.*, 2009).

This paper was originally presented and reviewed at a loggerhead sea turtle Recovery Potential Assessment Meeting, held in St. Andrews in February, 2010. This document also includes supplemental work completed during the meeting (Appendix A).

MATERIALS AND METHODS

Landings and Observer Data (Trip Level Aggregations)

Commercial landings data (within and outside the Canadian Exclusive Economic Zone (EEZ)) from Maritimes and Newfoundland regions were examined for the years 2002 through 2008. The Industry Surveys Database (ISDB) was queried for all observed trips on longline vessels undergoing normal fishing operations in Canadian waters, targeting swordfish and tunas (albacore, bigeye or yellowfin). Observer data from 2009 were incomplete at the time we started this work, and therefore we included data through 2008 only. Prior to 2001, loggerhead sea turtle encounters were coded as sea turtles in the ISDB. Given the issues of prompt data availability, combined with mis-identification of loggerhead sea turtles prior to 2001, we utilized data from 2002 through 2008 for our analyses.

Three observed trips were excluded from the dataset because they were not considered representative of normal fishing activity due to damaged gear (trips coded with invalid hauls). In addition, seven observed trips were excluded because they were from trips that were chartered by France using quota from St. Pierre et Miquelon. These trips were incorrectly coded as Canadian trips in the ISDB. Canadian vessels were chartered and therefore as a condition of licence they were required to carry observers on a portion of the trips. Fishing occurred outside of the Canadian EEZ; although Canada does have copies of logbook records from these trips, the landings data are not entered electronically or held in the commercial landings database.

In total, 101 observed trips were matched to commercial landings data for inclusion in our analyses. Set-level data were aggregated to the trip level because of difficulties encountered when attempting to match landings and observer data at the set level. This level of aggregation makes the use of set-level details such as water temperature and bait type more difficult. To examine the impact of trip-level aggregation of data, we determined that on tuna-targeted trips, the median percentage of sets with the same designation is typically greater than 70% (Figure 4).

Observer Data (Set Level Aggregations)

Set-level encounter rates of loggerhead sea turtles in the Canadian fishery were compared with other published estimates from trips made in the same time and area. The USA pelagic longline fishery to some extent overlaps with the Canadian fishery in the areas known as the Northeast Central (NEC) and Northeast Distant (NED, Figure 5a). The USA fishery primarily targets swordfish (G. Diaz, NMFS, pers. comm.). Canadian data were selected from the ISDB for positive loggerhead sea turtle encounters only, for the period 2005 through 2007, and aggregated by year and area to match that of the USA, as provided in Fairfield-Walsh and Garrison (2006), Fairfield-Walsh and Garrison (2007) and Fairfield and Garrison (2008) for 2005, 2006 and 2007, respectively.

Approaches for Estimating Fleet-Wide Loggerhead Sea Turtle Encounters

Delta-Lognormal Approach

A delta-lognormal generalized linear model (GLM) was used to predict the number of sea turtles encountered by the Canadian swordfish and tuna longline fleet. This same approach was used by Garrison et al. (2009) in their assessment of the by-catch of sea turtles by the U.S. Atlantic pelagic longline fleet during 2008.

The delta-lognormal approach has two component models used to handle different aspects of the encounter data. The presence-absence (1, 0) aspect of the encounters uses a model with a binomial error distribution. This component identifies the probability of an encounter. The second component deals with the positive encounters (>0). The encounters are standardized by the number of hooks and the resultant ratios are log-transformed. This component uses a model with lognormal errors and accounts for the magnitude of the encounters.

In the USA assessment, only quarter and region were used as stratifying variables for a given year. A complementary approach for the Canadian trip-level data was to stratify by quarter and region also, recognizing that the geographical regions defined in the USA assessments are much larger and quite distinctive compared to our own. Given the need to view the annual history of loggerhead sea turtle encounters in the Canadian data, all years (2002 – 2008) were retained.

Two geographically-distinct areas were defined based on the distribution of landings for the Canadian assessment, where the boundary between them was a line that bisected the Laurentian Channel and continued in a south-easterly direction. The areas were termed North and South based on their relationship to the boundary (Figure 5b).

The quarter years were defined in the conventional way but only quarters 2 to 4 were present in the data. The effort variable was defined as the number of hooks used per trip and since it was used to standardize the encounters in the lognormal component of the model, it was included as a descriptor in the binomial model as well.

The formula for the binomial model was:

$$\text{encounter}_{0,1} \sim \text{quarter} + \text{region} + \text{hooks},\ B(n,p)$$

and the lognormal model was:

$$\log_{10}(\text{encounters/hook}) \sim \text{quarter} + \text{region} + \text{quarter*region},\ \text{Log-N}(\mu,\sigma^2).$$

Ratio Estimation Approach

Ratio estimation was used by Brazner and MacMillan (2008) to predict loggerhead sea turtle encounters in the Canadian swordfish and tuna longline fishery. Using this approach, encounters in the observed portion of the fishery are used to estimate encounters by the entire fishery using the ratio of some variable common to both groups of data. Brazner and MacMillan (2008) used the weight of total commercial landings in both groups to scale the encounters observed to the entire fishery. This approach was applied within distinct strata such as year, season and region.

Using Brazner and McMillan's (2008) strata and scaling criteria, the estimation process was repeated on the same data. This initial model was subsequently altered, changing the stratification scheme and scaling variable until it included only the strata and prorating variable (number of hooks) used in the U.S. assessment of turtle encounters.

In the model equivalent to Brazner and McMillan's (2008) (model 4), the stratifying variables were year (2002 to 2008), quarter (Q2, Q3, Q4) and region (Grand Banks, Central, Western Scotian Shelf (WSS)-Georges) (Figure 5c) with landings (total weight of swordfish, shark and tunas) used as the prorating variable. The next model (model 3) used the number of trips to prorate the observed catch. Model 2 dropped years as a stratifying variable and changed the definition of region to the one used in the delta-lognormal approach above. Lastly, in model 1, the prorating was changed to the number of hooks used per trip.

Delta-Lognormal Approach with Targeting

The choice of stratifying variables may be influenced by personal bias. An objective approach is to allow an unsupervised process make the selections for us. We chose to let a decision tree select the stratifying variables. The top three variables identified were yellowfin tuna catch number, a grouping of Northwest Atlantic Fisheries Organization (NAFO) unit areas and total tuna weight. With NAFO unit areas removed, month was identified. These selections were incorporated in a delta-lognormal model. The two new regions were denoted ‘Offshore’ (NAFO subareas 3NE, 3OC, 3OE, 3OF, 4VSV and 4WW) and ‘Other’ (all other NAFO subareas) (Figure 5d). Using a threshold of 20.5 yellowfin tuna per trip, a targeting variable with two levels (Low = below 20.5, High = above 20.5) was created. The new yellowfin tuna variable was considered a proxy for target species. Quarter was used instead of month to reduce the number of levels representing season.

The formula for the binomial model was:

$$\text{encounter}_{0,1} \sim \text{quarter} + \text{region} + \text{yellowfin}, \ B(n,p)$$

and the lognormal model was:

$$\log_{10}(\text{encounters/hook}) \sim \text{yellowfin} + \text{quarter} + \text{region} + \text{quarter*region}, \ \text{Log-N}(\mu,\sigma^2).$$

RESULTS

Exclusion of Observer Data

The locations of the observed sets excluded from the analysis are illustrated in Figure 6a. A total of 80 loggerhead sea turtles were observed in the area south of Georges Bank on the three trips which were excluded due to invalid haul codes (Figure 6b). On the St. Pierre and Miquelon chartered trips, a total of 85 loggerhead sea turtles were observed on the edge of the Grand Banks and, to a lesser extent, east of the area (Figure 6b).

Examination of Observer Set Data

The spatial distribution of the observed sets appears to represent that of fishing sets when all years are combined (Figure 7); however, in most years there are areas where observer coverage is scarce, in particular in the offshore component of the fishery (Figure 8). Loggerhead sea turtle encounters over the time period in question are associated primarily with the offshore component both in the west and the east (Figure 9). Annually, the spatial distribution appears to be relatively consistent in recent years, observed largely in NAFO area 4W (Figure 10). The annual proportion of logbook sets attributed to tuna targeting has ranged from 0.42-0.62, while the annual proportion of observed sets attributed to tuna targeting has ranged from 0.18-0.50 (Table 1).

Average encounter rates of loggerhead sea turtle declined from 2002 to 2004, and increased in 2006, remaining high through 2008 (Figure 11). The recent increase corresponds to a decline in the number of sets observed, and is attributed to tuna-targeted sets. The number of observed sets increased monthly over the time period, peaking in August and declining steadily thereafter (Figure 12). The highest average encounter rates occurred in June (on swordfish-targeted sets) and in August and September (on tuna-targeted sets).

On observed sets, swordfish were caught in water temperatures between 12-23˚C, and 59% were caught between 16-19˚C. Twenty one percent of the observed swordfish catch occurred in temperatures where no loggerhead sea turtles were encountered (Table 2, Figure 13).

Albacore and bigeye tunas were primarily caught in 18-19˚C water, while the majority of yellowfin tunas were caught in 20˚C or greater. Seventy nine percent of loggerhead sea turtles were caught in temperatures which coincided with 97% of the yellowfin tuna caught on observed sets.

Comparison of Nominal Loggerhead Sea Turtle Encounter Rates by the USA and Canadian Fleets

Table 3 compares loggerhead sea turtle encounter rates by the two fleets, disaggregated into the NED and NEC areas, and by year (Figure 5c). There were no positive encounters in the NED for the USA fleet in 2005, and for Canada in 2006. Considering the available data, the USA encounter rates tended to be higher in the NED compared with the NEC in 2006 and 2007, but the differences were not significant (Mann-Whitney U, p = 0.125). In general over the 2005 to 2006 period, the median Canadian encounter rates were higher than those in the USA fishery (Mann-Whitney U, p 0.014).

Considering that the USA fishery largely targets swordfish, while the Canadian fishery targets either swordfish or tunas, we further disaggregated the Canadian data into the two target groups (Table 4). The portion of the Canadian fleet targeting swordfish had lower median encounter rates than did that portion targeting tunas (Mann-Whitney, p<0.001). However, the Canadian fleet targeting swordfish had similar median encounter rates to the USA fleet (Mann-Whitney U, p=0.363).

Observed Loggerhead Sea Turtle Encounters

The observer data consisted of 1632 trips spanning seven years of swordfish and tuna longline fishing from 2002 to 2008. Of the 1632 trips, 101 were accompanied by an observer who recorded the encounters with loggerheads (Table 6). This represents 6.2% coverage over the 7 year period. The distribution of the observations relative to year and quarter is shown below (Table 5). The distribution of the observed trips relative to year and quarter is shown in Table 7. The observers witnessed 483 encounters with loggerhead sea turtles during the 7 years. The distribution of encounters is shown for the total number of encounters, the number of distinct trips encountering sea turtles and the encounters per trip in each quarter and year (Tables 8-10). The distribution of the number of hooks used is relevant to understanding the trends in the observed and predicted number of loggerhead sea turtles caught. About 7% or 111 of the 1632 trips contained no effort (hook) information. Rather than drop these records, hook numbers were imputed using iterative regression imputation. The total number of hooks is described in Tables 11-13.

Delta-Lognormal Approach

The summary of coefficients for the binomial model indicated that the errors from the model are only slightly over-dispersed (i.e. 106.81/96 is slightly greater than 1) (Table 14). Consequently, hypothesis testing using chi-square tests were justified. The summary also showed significant parameter estimates for quarter, region and hooks. Thus there were significant differences between quarters and regions for the mean proportion of encounters and a significant relationship between the proportion of encounters and the number of hooks. An analysis of deviance verifies that this model accounts for a significant portion of the null deviance ($P(>|X^2|) = 0$). The mean proportion of encounters by region was South: 0.413 and North: 0.286 and by quarter Q2: 0.632, Q3:0.419 and Q4:0.050.

The lognormal model parameter estimates for quarter and the quarter*region interaction account for significant amounts of variation in the positive encounters. The model could be simplified by dropping region but not the quarter*region interaction. The mean response (back-transformed to catch-per-unit-effort (CPUE)) by quarter was Q2: 0.446, Q3: 0.892 and Q4:1.561 and by region South: 0.828 and North: 0.463. The mean response for the region*quarter interaction shows that the North experiences a higher encounter rate in the second quarter whereas in the south encounters peak during the third quarter (Table 15).

The product of the back transformed binomial and $\log_{10}$ predictions produced a predicted CPUE which yielded the number of predicted encounters per trip when multiplied by the number of hooks used on a trip. These predictions show a declining number of encounters in the north region (Figure 14, 18) which was observed to catch the bulk of its turtles in the second quarter (see Table). Consequently, second quarter results also show a decline in encounters over time.

Observed encounters by region:

	South	North	sum
Q2	45	66	111
Q3	338	7	345
Q4	27	0	27
sum	410	73	483

The third quarter has the most encounters and the trend seems to correspond with fishing activity in the south region. Except for a spike in encounters in 2006, the trend in the south is for encounters to decline.

Ratio Estimation Approach

The pro-ration results for models 4 and 3 are shown in Figure 15 with model 3 shown on top. The encounter time series resemble each other. Both models resulted in the largest predicted encounters of turtles by region in the WSS-Georges Bank area. The predicted encounters by year show sensitivity to single trips with a large number of observed turtles. The high prediction for 2006 results from a combination of a large encounter rate in the observed data (36/trip), and large total effort, both in trips and hooks. Predictions based on landings as effort reduce the number of encounters compared to using the number of trips or the number of hooks (Figures 15, 18).

The predictions of turtle encounters from models 2 and 1 had a similar yearly trend whether the effort was based on the number of hooks or the number of trips (Figure 16). An offset is introduced by higher third quarter predictions when effort is the number of trips. Regional predictions show a higher number of encounters in the south but there were a higher number of observed encounters in the second quarter in the north as shown in the table below (Figures 16, 18).

Observed encounters by region:

	South	North	sum
Q2	45	66	111
Q3	338	7	345
Q4	27	0	27
sum	410	73	483

Delta-Lognormal Approach with Targeting

The mean proportion of encounters declined from the second to forth quarter; Q2: 0.632, Q3: 0.419, Q4: 0.050. The mean proportion of encounters was highest in the special area, offshore compared the remainder; Other: 0.337, offshore: 0.889 and they were highest when yellowfin tuna catch numbers were high; High: 0.909, Low: 0.322.

The summary of the binomial model (Table 16) indicates that it is not over dispersed and that the mean proportions within quarter, area and yellowfin tuna are significantly different. The lognormal model shows significant differences in the mean encounter rate for the main effects of region, quarter and yellowfin tuna with an indication of differences between certain quarter area combinations.

The mean response (CPUE) for each quarter was Q2: 0.690, Q3: 0.866 and Q4: 1.561 and by region Other: 0.737 and offshore: 1.188. The mean response for levels of yellowfin tuna was High: 1.501 and Low: 0.598.

By quarter and region the mean response is highest for the second quarter in the offshore region and for the fourth quarter in the Other areas.

Region/Quarter	Q2	Q3	Q4
Other	0.195	0.867	1.56
Offshore	1.383	0.863	NA

The time series of total encounters by year indicate that the offshore region accounts for a sizeable proportion of the predicted turtle encounters since 2005 (Figure 17, 18**)**. Both regions show a decline in predicted encounters since 2006. The second quarter shows the same trend as the offshore region and the third quarter seems to be responsible for the trend in the Other region.

DISCUSSION

Encounter Rates and Factors Influencing Them

The annual spatial distribution of observed trips most closely represented that of the fishery in 2002, when the percent of observed trips covered was highest. In the same year, the proportion of observed sets made on the swordfish and tuna components of the fishery were most representative of those from the landings data. These may be important considerations when contemplating the adequacy of observer coverage for future analyses such as these.

The large increase in encounter rates in 2006 through 2008 is not fully explained by the modeling exercises we have considered in this working paper. Since the increase in these years is attributed largely to tuna-designated trips, there may be an important interaction between variables such as year and targeting, which were not explored here.

Our work showed that targeting of tunas is an important correlate of encounter rates of loggerhead sea turtles, with higher encounter rates of loggerheads observed when the fleet targets tunas. For the fleet targeting swordfish, the encounter rates over the 2005 through 2007 period were comparable to published reports for the USA pelagic longline fishery.

Estimates of Total Encounters by the Canadian Fleet

The delta-lognormal approach with region and quarter as stratifying variables predicts almost 50% fewer loggerhead sea turtle encounters than applying ratio estimation within the same strata. This appears to be the primary difference between the approaches as the trends both within and across years appear quite similar (Figure 18). Ratio estimation is optimal when there is a strong positive relationship between the auxiliary variable and the response, especially when the relationship is linear through the origin. In this case, hooks per trip and number of loggerhead caught had a correlation of 0.39 with the zeros catches and 0.46 with catches greater than zero. These correlations are marginal and while they are also important to the delta-lognormal model, its two component approach takes advantage of the stronger relationship between hooks and the number of turtle caught for the positive encounters.

The lower predicted annual number of encounters resulting from the delta-lognormal approach can be attributed to the binomial proportions scaling back the effort in strata where turtles were not observed. That is, the delta-lognormal model attempts to make predictions using only that portion of the total fleet that typically encounters turtles.

The ratio estimation approach proved sensitive to a small number of large catches (outliers) in a stratum whereas the lognormal transformation of encounter rate by the delta lognormal model addresses the non-normal distribution of the response. Thus the delta-lognormal approach tended to provide stable predictions for a targeted segment of the total fleet's effort.

Brazner and MacMillan (2008) used the ratio estimation approach to predict encounters and model 4 in this paper closely approximates their methodology. As described above, the approach requires a strong positive correlation between the response and the auxiliary variable. We observed a correlation of 0.13 between total landings and the number of loggerhead caught. With such weak relationships between the auxiliary variable and the response variable the method is less desirable than the ratio estimation approach above based on hooks. The extra stratification due to year and an extra region makes the estimates more prone to outliers. The predictions from model 4 (Figure 4) have the second largest change from year to year and also the second largest total number of encounters by any model presented here. Model 3, which used trip number as the auxiliary variable, had the largest number of encounters.

In general the ratio estimation results indicate that changing the auxiliary variable affects the predictions less than increasing the number of strata and consequently models with few strata are to be preferred.

The objective selection of variables for a delta-lognormal model improved the overall fit to the encounter data, and indicated that a time and area effect could be important. Making appropriate area and time groups was facilitated by the objective approach as can be seen by the resulting enhanced relationship between time and area.

The identification of yellowfin tuna catch numbers as a third explanatory variable important to explaining loggerhead sea turtle encounters also agreed with our intuition that a targeting variable might be necessary, yet the selection of yellowfin tuna and a threshold value in particular were not anticipated. Despite the better fit using an unsupervised selection of variables, one must be sure that the selections and their levels make sense. Generally, the grouping of areas and use of yellowfin tuna catch seemed appropriate.

The contrasting approaches employed to predict the number of loggerhead sea turtle encounters (Figure 18) provided a range of between 4 and 9 thousand encounters between

2002 and 2008. All the predictions made by ratio estimation were high yet they showed essentially the same trends as the delta-lognormal approach when stratified in the same way. The lower predictions from the delta-lognormal approach are preferred because only the effort associated with turtle encounters contributes to the prediction. However, ratio estimation could include sensible limits on effort.

Irrespective of the model, the limitations of the data and its impact on the predictions should be recognized. Poor or no coverage in certain strata can bias outcomes especially when populated with atypical data. The sensitivity of the predictions to influential observations and the unbalanced nature of the data should be explored for both the ratio estimation and delta-lognormal approaches.

Lastly, it should be noted that not all variables known to have an impact on loggerhead sea turtle encounters were available for inclusion in the models. The primary variables omitted included hook type, bait type, water temperature and bathymetry. These variables were available at the set level in the observer data base and may have no analogue in the commercial data base or cannot be represented at the trip level. Thus their incorporation in future assessments may have merit.

LITERATURE CITED

Brazner, J.C., and J. McMillan. 2008. Loggerhead turtle (*Caretta caretta*) by-catch in Canadian pelagic longline fisheries: Relative importance in the western North Atlantic and opportunities for mitigation. Fisheries Research 91(2-3):310-324.

Conant, T.A., P.H. Dutton, T. Eguchi, S.P.Epperly, C.C. Fahy, M.H. Godfrey, S.L. MacPherson, E.E. Possardt, B.A. Schroeder, J.A. Seminoff, M.L. Snover, C.M. Upite, and B.E. Witherington. 2009. Loggerhead sea turtle (*Caretta caretta*) 2009 status review under the U.S. Endangered Species Act. Report of the Loggerhead Biological Review Team to the National Marine Fisheries Service, August 2009: 222p.

Fairfield-Walsh, C., and L.P. Garrison. 2008. Estimated by-catch of marine mammals and turtles in the U.S. Atlantic pelagic longline fleet during 2007. NOAA. Technical Memorandum NMFS-SEFSC-572: 63p.

Fairfield-Walsh, C., and L.P Garrison. 2007. Estimated by-catch of marine mammals and turtles in the U.S Atlantic pelagic longline fleet during 2006. NOAA Technical Memorandum NMFS-SEFSC-560: 58p.

Fairfield-Walsh, C., and L.P. Garrison. 2006. Estimated by-catch of marine mammals and turtles in the U.S. Atlantic pelagic longline fleet during 2005. NOAA Technical Memorandum NMFS-SEFSC-539, 52p. {Updated May, 2006.}

Garrison, L.P., L. Stokes, and C. Fairfield. 2009. Estimated by-catch of marine mammals and sea turtles in the U.S Atlantic pelagic longline fleet during 2008. NOAA Technical Memorandum NOAA NMFS-SEFSC-591: 63p.

Paul, S., and J.D. Neilson. 2009. An Exploration of Targeting Variables in the Canadian Swordfish Longline CPUE. Int. Comm. Conserv. Atl. Tunas, SCRS/2009/031.

Table 1. Number and proportion of fishing sets from logbook and observer records by year and target species.

Year	Target	Logbook Number of sets	Logbook Proportion	Observed Number of sets	Observed proportion
2002	swo	422	0.5	142	0.5
	tun	428	0.5	141	0.5
2003	swo	337	0.58	85	0.82
	tun	240	0.42	19	0.18
2004	swo	339	0.44	56	0.75
	tun	431	0.56	19	0.25
2005	swo	418	0.57	46	0.65
	tun	319	0.43	25	0.35
2006	swo	249	0.38	82	0.66
	tun	400	0.62	43	0.34
2007	swo	261	0.39	60	0.79
	tun	405	0.61	16	0.21
2008	swo	256	0.45	27	0.79
	tun	319	0.55	7	0.21

Table 2. Proportion of species caught at temperature, based on estimated weights from observed sets (2002-2008).

Temperature (°C)	Loggerhead Turtle	Swordfish	Yellowfin Tuna	Bigeye Tuna	Albacore Tuna
10-11	0.00	0.01	0.00	0.00	0.00
12-13	0.00	0.05	0.00	0.01	0.00
14-15	0.00	0.15	0.00	0.01	0.01
16-17	0.07	0.29	0.00	0.12	0.09
18-19	0.14	0.30	0.03	0.51	0.67
20-21	0.18	0.13	0.26	0.11	0.08
22-23	0.24	0.07	0.39	0.10	0.10
24-25	0.36	0.01	0.25	0.13	0.05
26-27	0.01	0.00	0.07	0.01	0.00

Table 3. Summary statistics (count and average) of positive encounters of loggerhead turtles within Canadian and USA observer information, 2005-2007. The terms 'NEC' and 'NED' are geographic designations referring to Northeast Central and Northeast Distant regions respectively as used by the USA NMFS (see Fairfield and Walsh 2008). The bottom two panels show the loggerhead turtle encounter rates per 1000 hooks, summarized by country and quarter or country and year. Canadian data were selected from the ISDB for positive loggerhead turtle encounters only, for the years 2005 to 2007, and aggregated by year and area to match that of the USA, as provided in Fairfield-Walsh and Garrison (2006), Fairfield-Walsh and Garrison (2007) and Fairfield and Garrison (2008) for 2005, 2006 and 2007 respectively.

Count of LHT/1000 hks	Area Year								
	NEC			NEC Total	NED			NED Total	Grand Total
Country	2005	2006	2007		2005	2006	2007		
CAN	10	32	12	54	9		7	16	70
US	7	12	2	21		11	15	26	47
Grand Total	17	44	14	75	9	11	22	42	117

Average of LHT/1000 hks	Area Year								
	NEC			NEC Total	NED			NED Total	Grand Total
Country	2005	2006	2007		2005	2006	2007		
CAN	2.07	3.11	2.63	2.81	0.90		3.01	1.82	2.59
US	1.78	1.16	0.98	1.35		2.22	2.31	2.27	1.86
Grand Total	1.95	2.58	2.39	2.40	0.90	2.22	2.53	2.10	2.29

Average of LHT/1000 hks	Quarter			
Country	2	3	4	Grand Total
CAN	1.65	2.76		2.56
US	1.13	2.01	1.34	1.86
Grand Total	1.58	2.47	1.34	2.28

Mean LHT by country and quarter

Average of LHT/1000 hks	Year			
Country	2005	2006	2007	Grand Total
CAN	1.47	3.11	2.77	2.56
US	1.78	1.67	2.15	1.86
Grand Total	1.55	2.51	2.48	2.28

Mean LHT by country and year

Table 4. Summary statistics (count and average) of loggerhead turtle encounter rates in the Canadian and USA fisheries as obtained from observer information onboard both fleets. The data are further disaggregated by the target species in the Canadian fishery, with ‘1’ signifying sets that targeted swordfish, and ‘2’ signifying sets that targeted tropical tunas. Canadian data were selected from the ISDB for positive loggerhead turtle encounters only, for the years 2005 to 2007, and aggregated by year and area to match that of the USA, as provided in Fairfield-Walsh and Garrison (2006), Fairfield-Walsh and Garrison (2007) and Fairfield and Garrison (2008) for 2005, 2006 and 2007 respectively.

Count of LHT/1000 hks		Area	Year									
		NEC			NEC Total	NED			NED Total	(blank)	(blank) Total	Grand Total
Country	Target	2005	2006	2007		2005	2006	2007		2005		
CAN	1	6	4	9	19	9			9	1	1	29
	2	4	28	3	35			7	7			42
CAN Total		10	32	12	54	9		7	16	1	1	71
US	(blank)	7	12	2	21		11	15	26			47
US Total		7	12	2	21		11	15	26			47
Grand Total		17	44	14	75	9	11	22	42	1	1	118

Average of LHT/1000 hks		Area	Year									
		NEC			NEC Total	NED			NED Total	(blank)	(blank) Total	Grand Total
Country	Target	2005	2006	2007		2005	2006	2007		2005		
CAN	1	1.77	1.60	1.72	1.71	0.90			0.90	0.66	0.66	1.42
	2	2.51	3.33	5.37	3.41			3.01	3.01			3.34
CAN Total		2.07	3.11	2.63	2.81	0.90		3.01	1.82	0.66	0.66	2.56
US	(blank)	1.78	1.16	0.98	1.35		2.22	2.31	2.27			1.86
US Total		1.78	1.16	0.98	1.35		2.22	2.31	2.27			1.86
Grand Total		1.95	2.58	2.39	2.40	0.90	2.22	2.53	2.10	0.66	0.66	2.28

Table 5. Number of trips prosecuted by the Canadian pelagic long line fishery by year and quarter.

Year	Q2	Q3	Q4	sum
2002	41	162	21	224
2003	33	155	29	217
2004	29	196	29	254
2005	37	195	23	255
2006	40	202	35	277
2007	41	167	16	224
2008	29	142	10	181
sum	250	1219	163	1632

Table 6. Number of trips prosecuted by the Canadian pelagic long line fishery that were witnessed by an observer. Summary by year and quarter.

Year	Q2	Q3	Q4	sum
2002	10	20	8	38
2003	2	8	4	14
2004	2	7	1	10
2005	1	7	1	9
2006	1	9	5	15
2007	2	7	1	10
2008	1	4	0	5
sum	19	62	20	101

Table 7. The percentage of total trips prosecuted by the Canadian pelagic long line fishery that were witnessed by an observer. Summary by year and quarter.

Year	Q2	Q3	Q4
2002	24.4	12.3	38.1
2003	6.1	5.2	13.8
2004	6.9	3.6	3.4
2005	2.7	3.6	4.3
2006	2.5	4.5	14.3
2007	4.9	4.2	6.2
2008	3.4	2.8	0.0

Table 8. The number of loggerhead turtle encounters witnessed by an observer during trips prosecuted by the Canadian pelagic long line fishery.

Year	Q2	Q3	Q4	sum
2002	75	63	27	165
2003	4	28	0	32
2004	1	4	0	5
2005	3	31	0	34
2006	7	144	0	151
2007	21	48	0	69
2008	0	27	0	27
Sum	111	345	27	483

Table 9. The number of distinct trips prosecuted by the Canadian pelagic long line fishery that were observed to have encountered at least one loggerhead turtle.

Year	Q2	Q3	Q4	sum
2002	6	9	1	16
2003	1	2	0	3
2004	1	2	0	3
2005	1	4	0	
2006	1	4	0	5
2007	2	4	0	6
2008	0	1	0	1
sum	12	26	1	39

Table 10. The number of observed loggerhead turtle encounters per trips prosecuted by the Canadian pelagic long line fishery.

Year	Q2	Q3	Q4
2002	12.50	7.00	27
2003	4.00	14.00	
2004	1.00	2.00	
2005	3.00	7.75	
2006	7.00	36.00	
2007	10.50	12.00	
2008		27.00	

Table 11. The total number of hooks (‘000) set by the Canadian pelagic long line fishery by year and quarter.

Year	Q2	Q3	Q4	sum
2002	407	1141	114	1663
2003	306	1215	137	1658
2004	255	1335	102	1691
2005	342	1348	84	1774
2006	263	1371	143	1778
2007	272	1105	55	1433
2008	213	906	55	1174
sum	2059	8422	691	11171

Table 12. The total number of hooks ('000) set by the Canadian pelagic long line fishery by year and quarter for which an observer was present.

Year	Q2	Q3	Q4	sum
2002	111	147	55	313
2003	19	86	14	119
2004	13	44	6	63
2005	10	64	3	76
2006	12	113	37	162
2007	14	64	5	83
2008	2	36	0	38
sum	182	553	120	855

Table 13. The percentage of hooks set by the Canadian pelagic long line fishery that had an observer present.

Year	Q2	Q3	Q4
2002	27.3	12.9	48.2
2003	6.2	7.1	10.2
2004	5.1	3.3	5.9
2005	2.9	4.7	3.6
2006	4.6	8.2	25.9
2007	5.1	5.8	9.1
2008	0.9	4.0	0.0

Table 14. Summary of coefficients for the binomial component of the delta lognormal model where the response is the proportion of positive trips, and is dependent upon quarter, region and the number of hooks.

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.3780     0.6965   -0.54   0.5873
qrt_sailQ3   -1.0675     0.5947   -1.80   0.0726 .
qrt_sailQ4   -3.4352     1.1829   -2.90   0.0037 **
regionNorth  -1.5865     0.6861   -2.31   0.0208 *
imp_hooks     0.1536     0.0559    2.75   0.0060 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 134.73  on 100  degrees of freedom
Residual deviance: 106.81  on  96  degrees of freedom
AIC: 116.8

Number of Fisher Scoring iterations: 5
```

Table 15. Summary of coefficients for the lognormal component of the delta lognormal model where the response is the log (CPUE) of the positive trips is dependent upon quarter, region and quarter*region.

```
-9.42e-01 -4.15e-01 -1.11e-16  4.02e-01  9.02e-01

Coefficients: (1 not defined because of singularities)
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)             -0.483      0.175   -2.76   0.0093 **
qrt_sailQ3               0.479      0.206    2.32   0.0265 *
qrt_sailQ4               0.676      0.553    1.22   0.2301
regionNorth              0.384      0.350    1.10   0.2797
qrt_sailQ3:regionNorth  -1.270      0.476   -2.67   0.0115 *
qrt_sailQ4:regionNorth      NA         NA      NA       NA
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.275)

    Null deviance: 12.5696  on 38  degrees of freedom
Residual deviance:  9.3633  on 34  degrees of freedom
AIC: 67.03

Number of Fisher Scoring iterations: 2
```

Table 16. Binomial and lognormal coefficients for a delta lognormal model in which both response variables (proportion positive and log (CPUE)) are dependent on region fished, quarter fished and the number of yellowfin tuna caught.

Model 3, binomial component

```
Call:
glm(formula = encounter ~ yfn_num + nafo_region + qrt_sail, family = "binomial",
    data = dglm_data)

Deviance Residuals:
   Min      1Q  Median      3Q     Max
-2.083  -0.878  -0.320   0.497   2.448

Coefficients:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)        2.686      1.207    2.23    0.026 *
yfn_numLow        -2.802      1.095   -2.56    0.010 *
nafo_regionHigh    2.148      1.141    1.88    0.060 .
qrt_sailQ3        -0.637      0.619   -1.03    0.303
qrt_sailQ4        -2.828      1.167   -2.42    0.015 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 134.73  on 100  degrees of freedom
Residual deviance: 100.47  on  96  degrees of freedom
AIC: 110.5

Number of Fisher Scoring iterations: 5
```

Model 3, lognormal component

```
glm(formula = log10(cpue) ~ yfn_num + nafo_region * qrt_sail,
    family = "gaussian", data = dglm_data, subset = num_caught_loggerhead >
        0)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.8129  -0.3086  -0.0120   0.3569   1.1871

Coefficients: (1 not defined because of singularities)
                           Estimate Std. Error t value Pr(>|t|)
(Intercept)                  -0.392      0.252   -1.56   0.1290
yfn_numLow                   -0.404      0.190   -2.13   0.0407 *
nafo_regionHigh               0.820      0.298    2.75   0.0095 **
qrt_sailQ3                    0.567      0.222    2.56   0.0153 *
qrt_sailQ4                    0.989      0.544    1.82   0.0783 .
nafo_regionHigh:qrt_sailQ3   -0.835      0.431   -1.94   0.0614 .
nafo_regionHigh:qrt_sailQ4       NA         NA      NA       NA
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.258)

    Null deviance: 12.5696  on 38  degrees of freedom
Residual deviance:  8.5298  on 33  degrees of freedom
AIC: 65.4
```

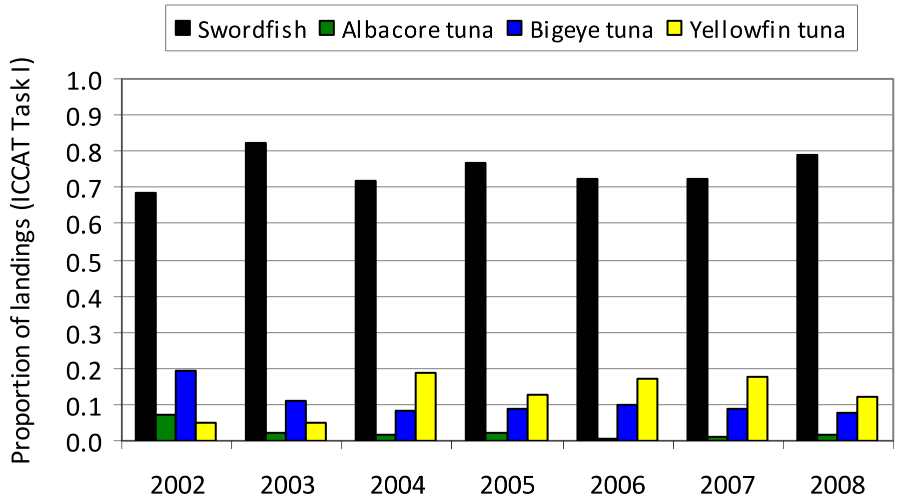


Figure 1. Proportion of swordfish and tuna species landed by the Canadian swordfish and tuna longline fishery between 2002 and 2008.

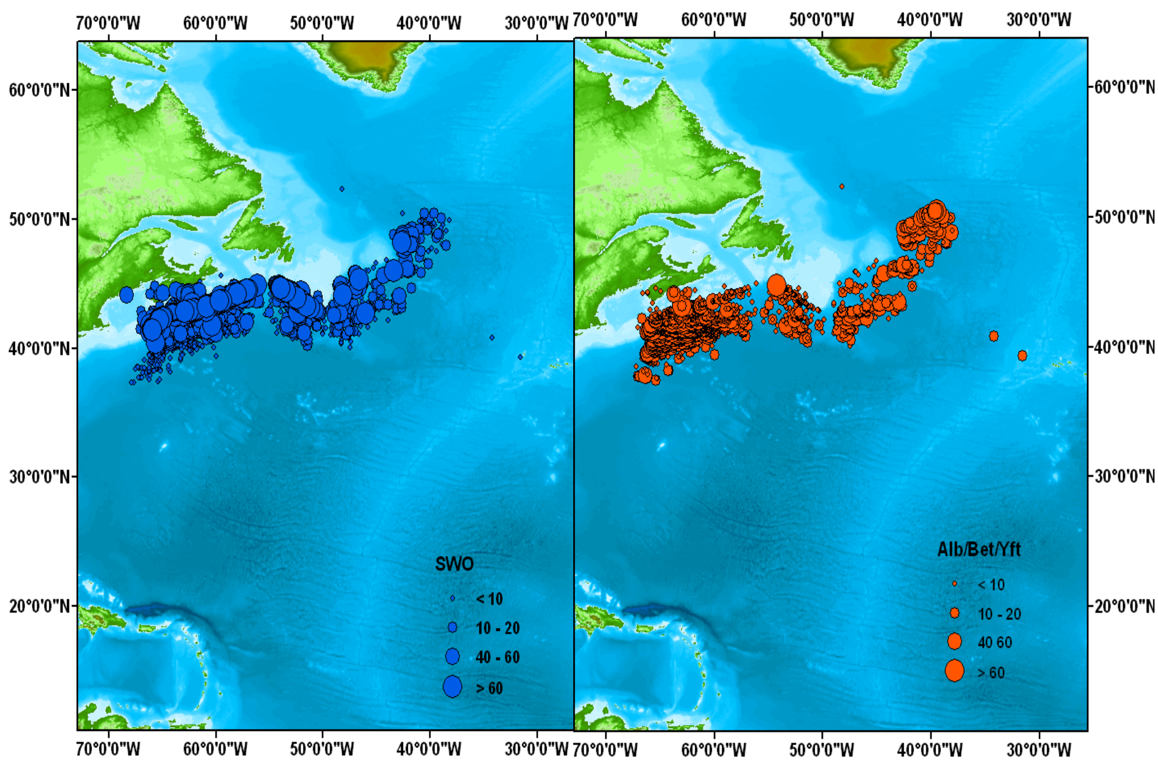


Figure 2. The distribution of swordfish (left panel) and tunas (right panel) catches by the Canadian swordfish and tuna longline fishery; from commercial logbook records, 2002-2008.

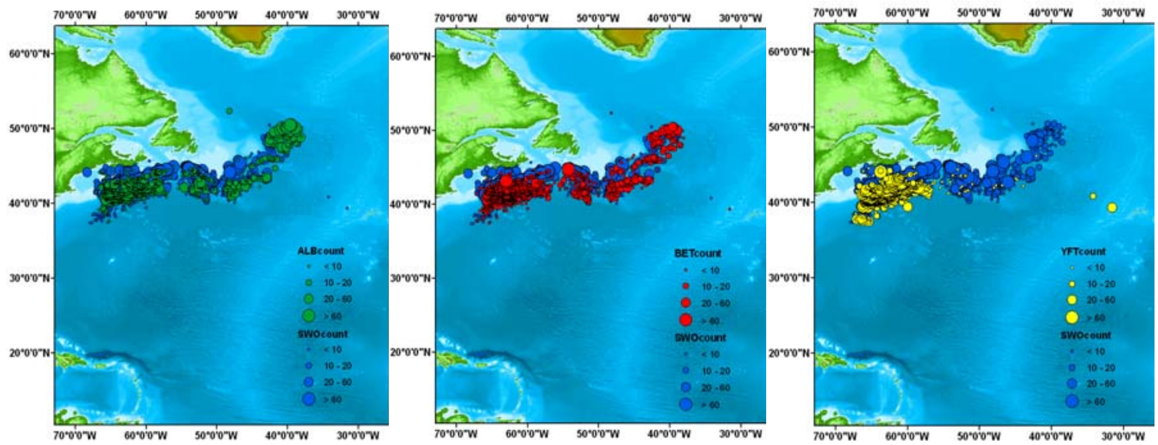


Figure 3. Catch distribution of albacore tuna (left panel), bigeye tuna (center panel) and yellowfin tuna (right panel) by the Canadian swordfish and tuna longline fishery; from commercial logbooks, 2002-2008. In each, swordfish catch is plotted in blue.

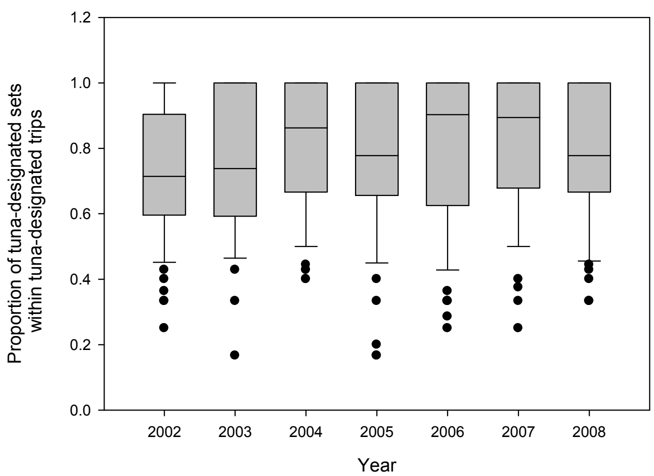


Figure 4. Proportion of tuna-designated sets within tuna-targeted trips, 2002-2008.

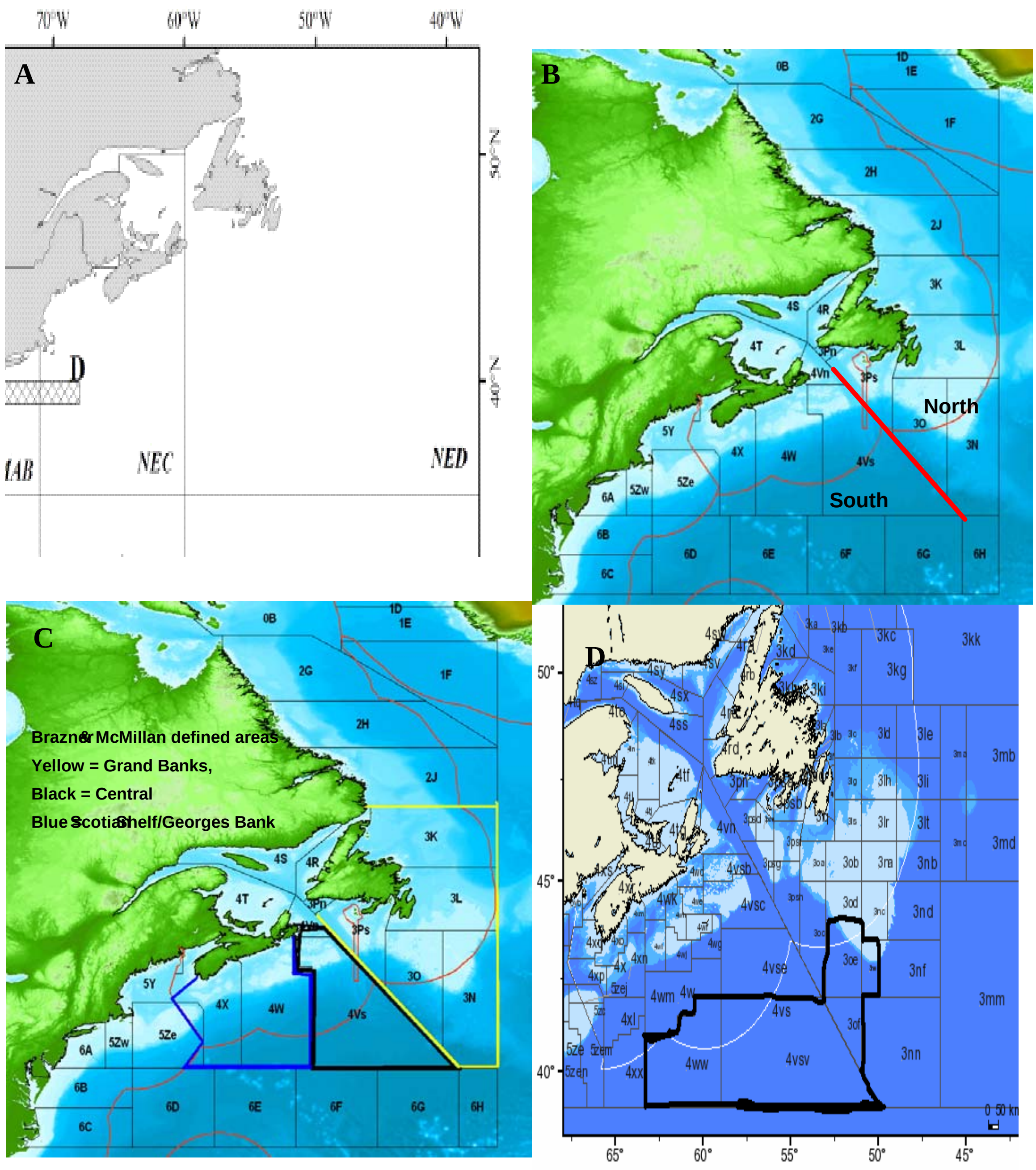


Figure 5. Study areas used in A) Northeast Distant (NED) and Northeast Coastal (NEC) areas as in Garrison *et al.* (2009), B) Delta-lognormal approach complementary to that used in Garrison *et al.* (2009), C) Ratio Estimation approached as in Brazner and MCMillan (2008), D) Delta-lognormal approach with targeting, which employed an unsupervised process to select stratifying variables.

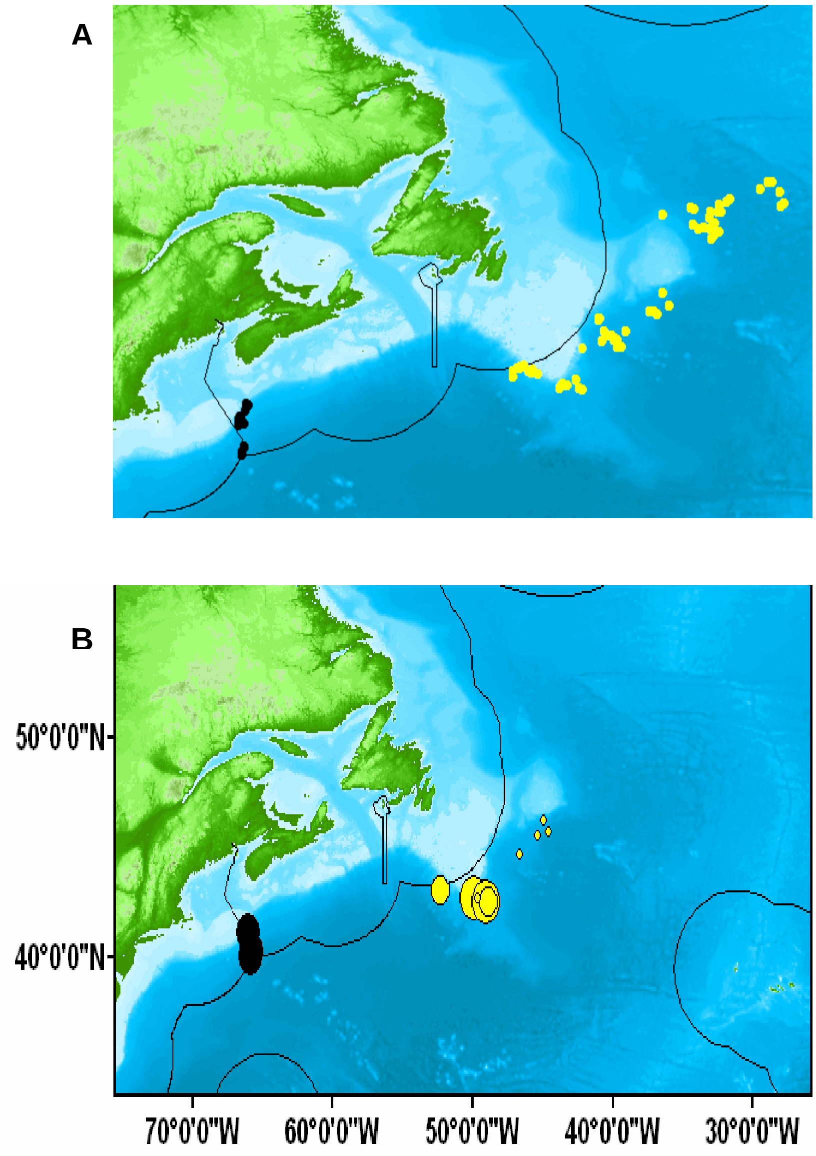


Figure 6. A) Location of observed sets excluded from the analysis, and B) location and number of loggerhead turtle encounters from observed sets excluded from the analysis.

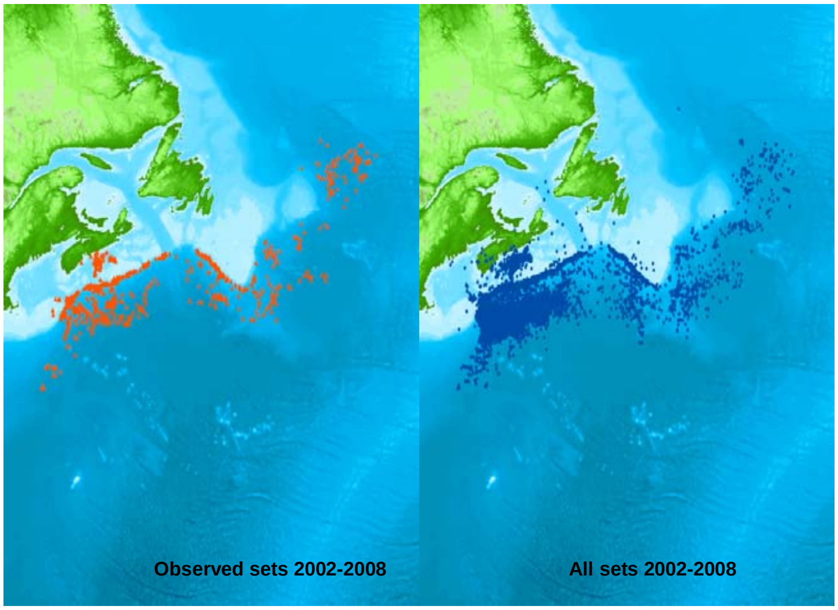


Figure 7. Spatial distribution of observed sets (left panel) and all longline sets (right panel) for the data 2002-2008.

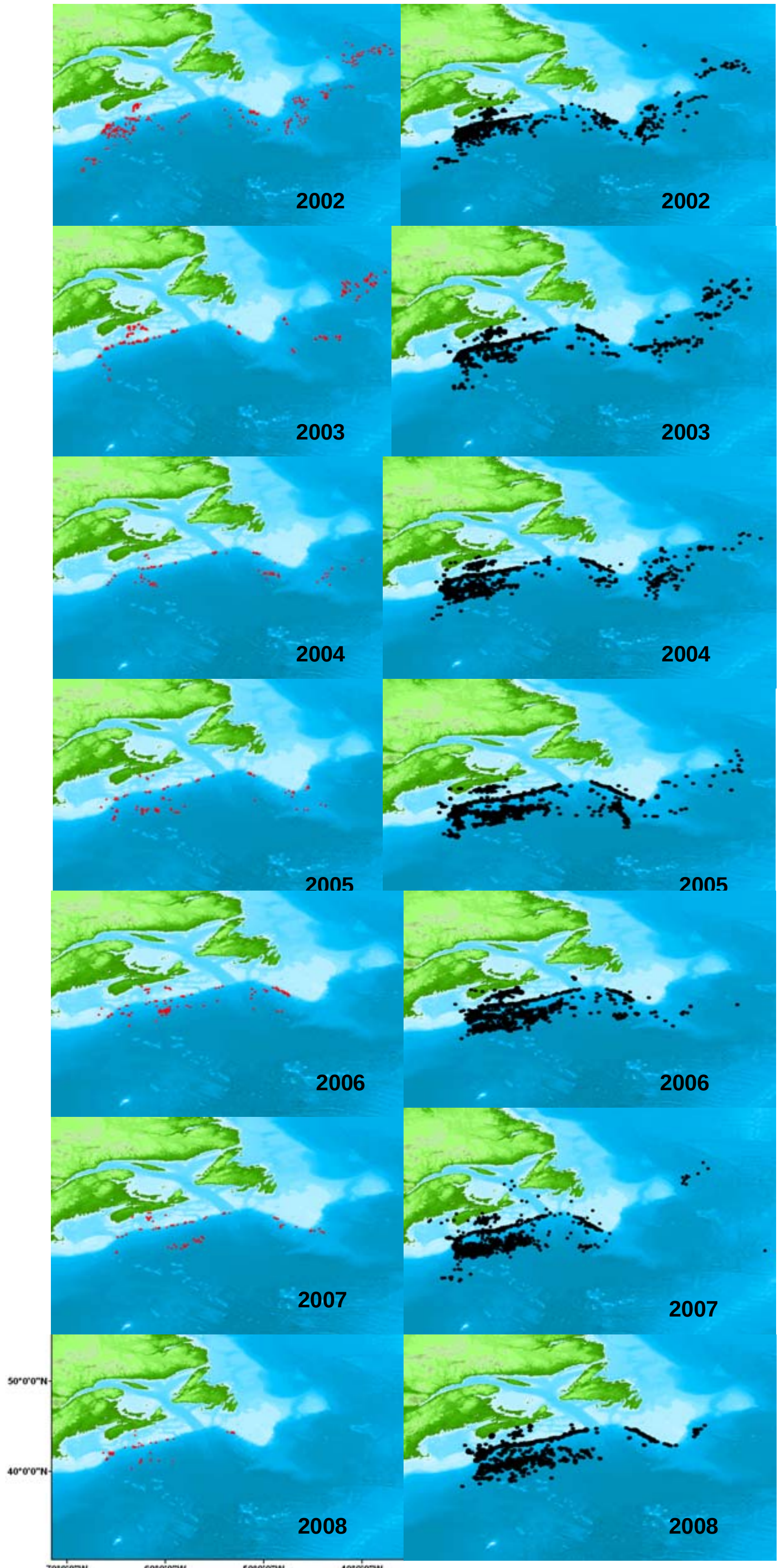


Figure 8. Spatial distribution of observed sets (left panel) and all longline sets (right panel) from 2002 – 2008.

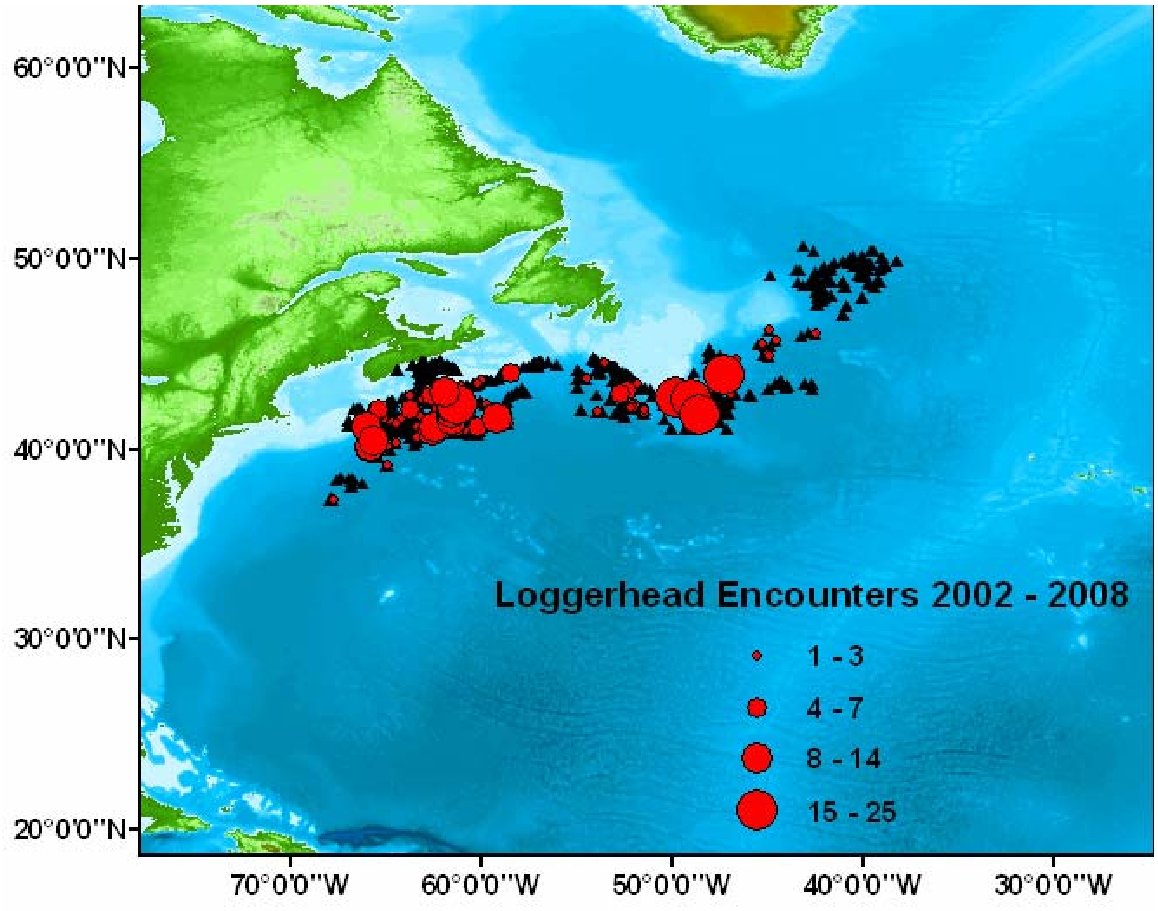


Figure 9. Spatial distribution of positive loggerhead turtle encounters (red) and all observed sets in Canadian swordfish and tuna longline fishery, 2002-2008.

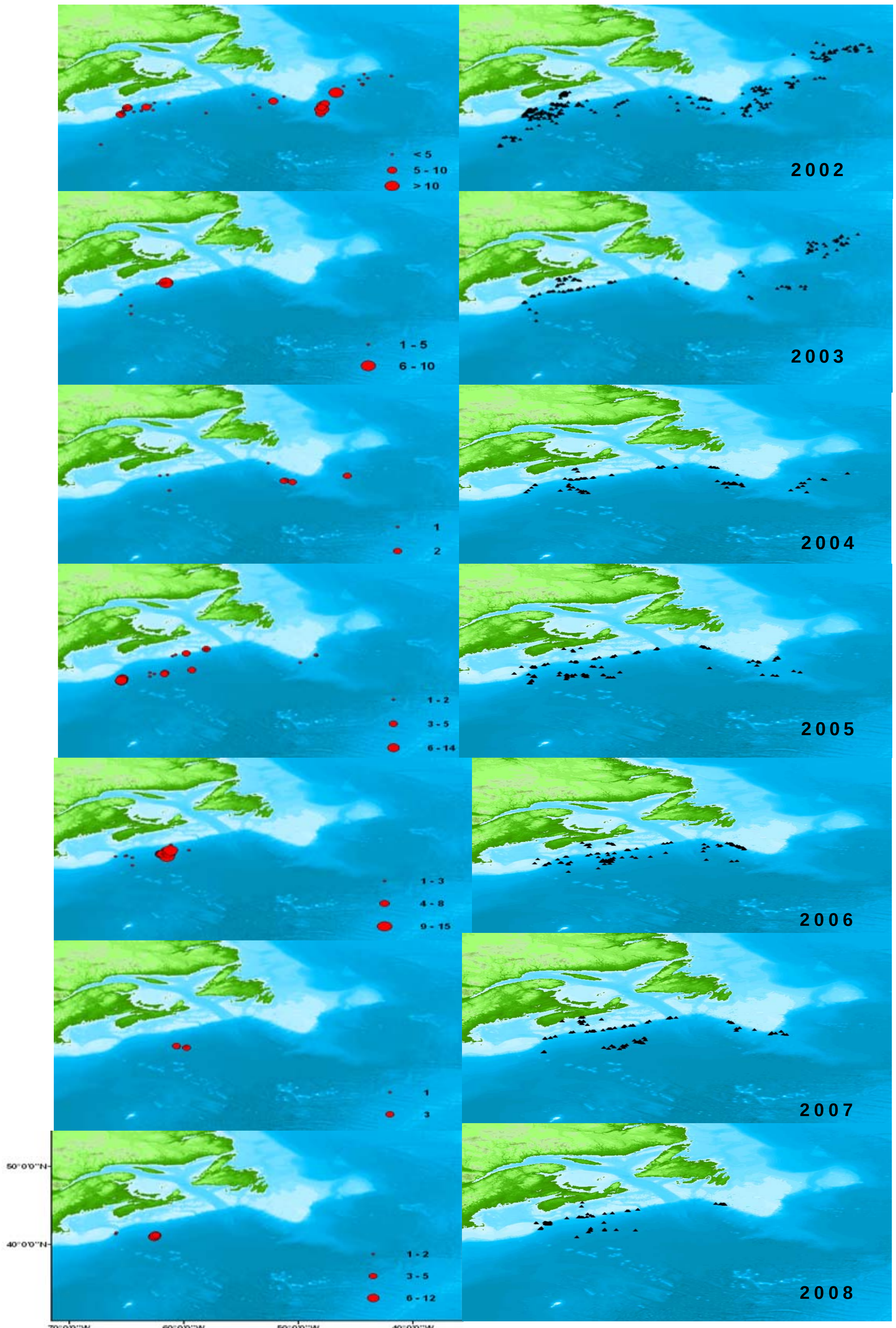


Figure 10. Spatial distribution of loggerhead turtle encounters (left panel) and all observed sets (right panel), 2002-08.

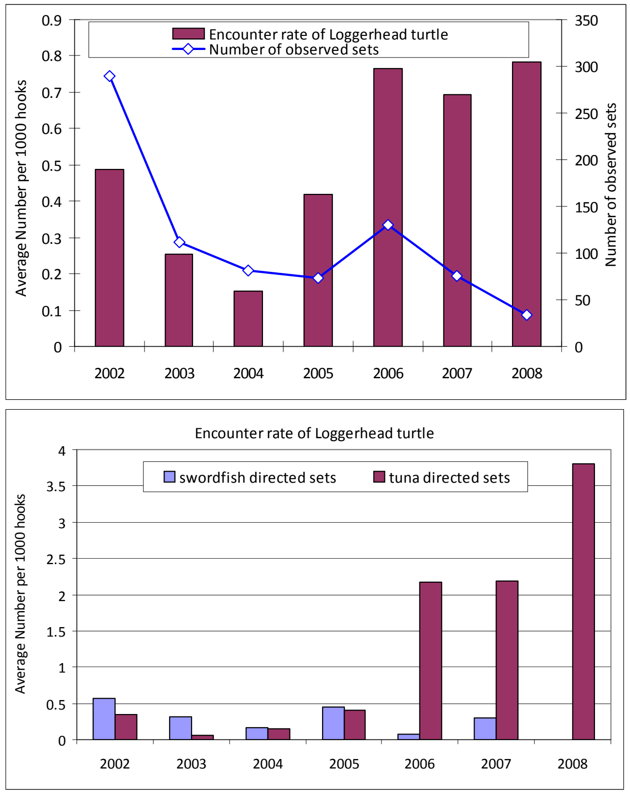


Figure 11. Average number of loggerhead turtles per 1000 hooks, shown with number of observed sets (top), and by targeted species (bottom), by year.

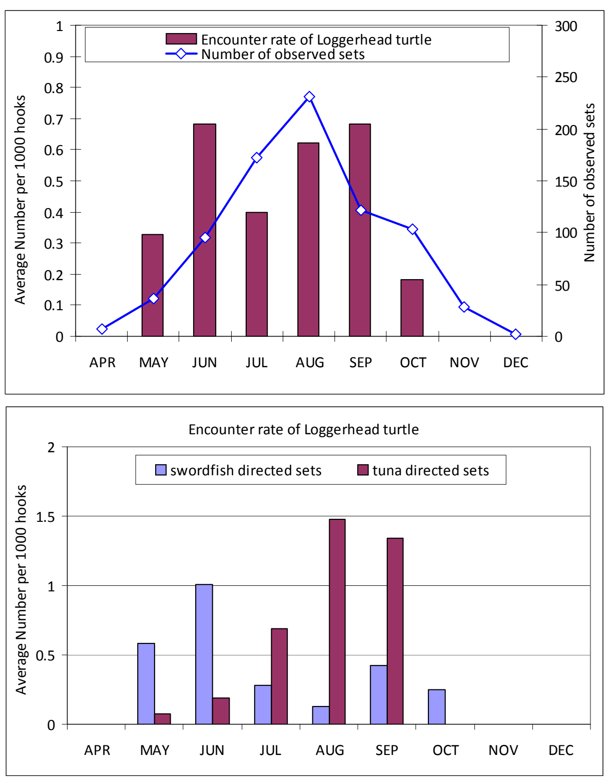


Figure 12. Average number of loggerhead turtles per 1000 hooks (2002-2008), shown with number of observed sets (top), and by targeted species (bottom), by month.

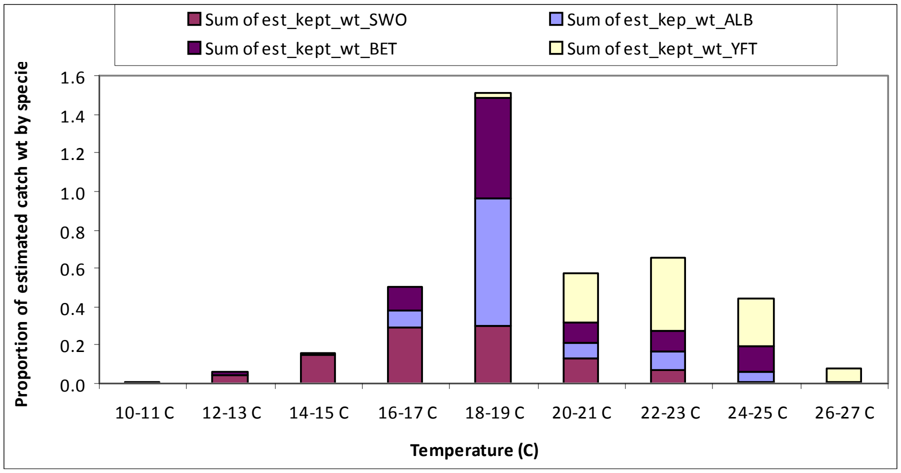
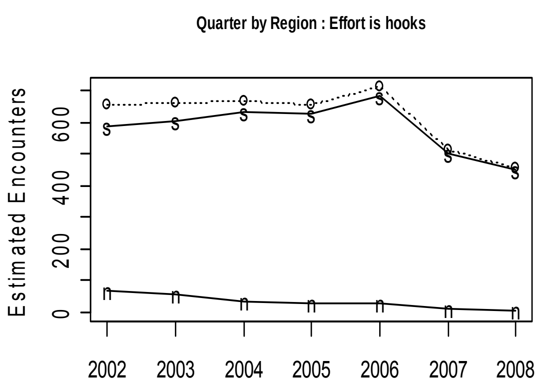
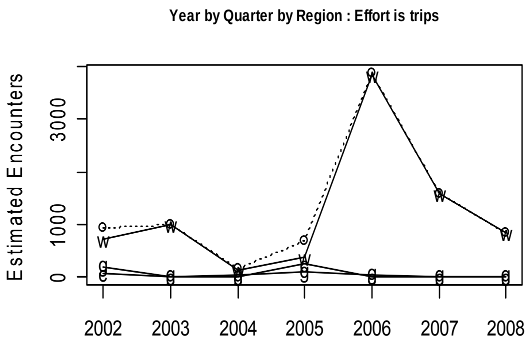


Figure 13. Proportion of estimated catch weight from observed sets (2002-2008) at temperature (°C); SWO = swordfish, ALB = albacore tuna, BET = bigeye tuna, YFT = yellowfin tuna.

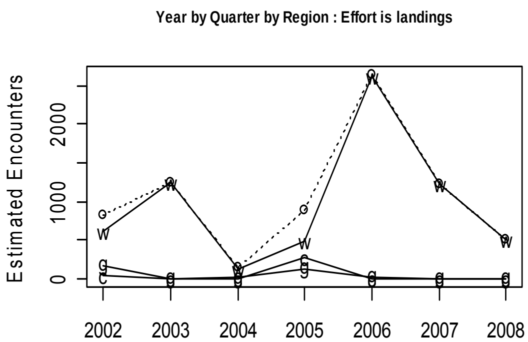


	2002	2003	2004	2005	2006	2007	2008	sum
Q2	133	96	70	92	68	65	50	574
Q3	507	551	588	556	630	441	396	3670
Q4	15	13	9	6	13	6	7	69
sum	655	660	667	654	711	512	453	4313

Figure 14. Predicted loggerhead turtle encounters by the Canadian long line fishery (dashed line) (2002 to 2008). Encounters are presented by region (n=north, s=south) and are shown relative to the total (dotted line). A summary of the encounters by quarter and year is shown in the table.

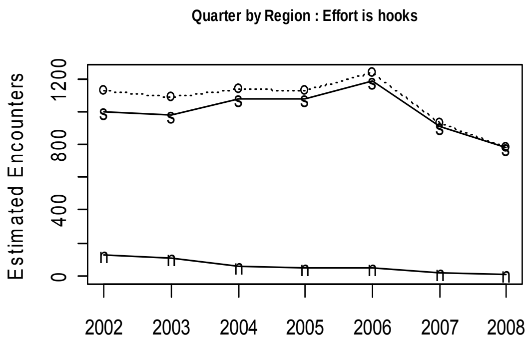


	2002	2003	2004	2005	2006	2007	2008	sum
Q2	231	92	23	12	28	399	0	785
Q3	614	896	120	666	3847	1168	837	8148
Q4	77	0	0	0	0	0	0	77
sum	922	988	143	678	3875	1567	837	9010

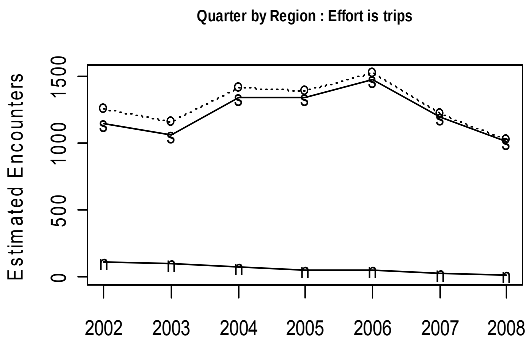


	2002	2003	2004	2005	2006	2007	2008	sum
Q2	216	236	18	32	22	362	0	885
Q3	543	1004	126	852	2613	868	498	6503
Q4	56	0	0	0	0	0	0	56
sum	815	1240	143	884	2634	1230	498	7444

Figure 15. Predicted loggerhead encounters using a ratio estimate approach (dashed line). Differences between regions are shown relative to the encounter time series for each approach. Regions are identified by symbol type (g=Grand Banks, c=Central and w=WSS/Georges Bank). Totals over region by quarter and year are presented to the right of each plot.

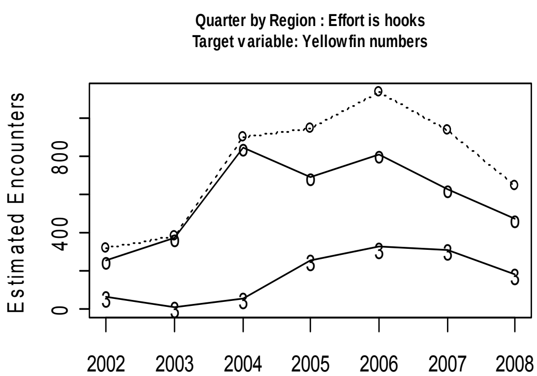


	2002	2003	2004	2005	2006	2007	2008	sum
Q2	233	182	133	160	133	116	87	1044
Q3	860	864	987	952	1063	794	677	6197
Q4	33	40	17	16	37	18	18	179
sum	1126	1086	1137	1128	1233	928	782	7420



	2002	2003	2004	2005	2006	2007	2008	sum
Q2	210	175	146	151	169	149	100	1099
Q3	1008	931	1221	1196	1291	1035	899	7581
Q4	34	46	39	32	54	27	17	248
sum	1251	1151	1405	1379	1513	1211	1016	8928

Figure 16. Predicted loggerhead encounters using a ratio estimate approach (dashed line). Differences between regions are shown relative to the encounter time series for each approach. Details regarding the extent of the regions are given in the text (s=South, n=North). Totals over region by quarter and year are presented to the right of each plot.



	2002	2003	2004	2005	2006	2007	2008	sum
Q2	87	32	92	95	179	250	188	923
Q3	217	297	802	847	942	684	455	4244
Q4	9	49	8	7	11	4	4	92
sum	312	378	902	949	1133	938	647	5259

Figure 17. Predicted loggerhead turtle encounters by the Canadian long line fishery using a ratio estimate approach (2002 to 2008). Encounters are presented by region (3=offshore, O=other) and are shown relative to the total (dotted line). A summary of the encounters by quarter and year is shown to the right of the plot.

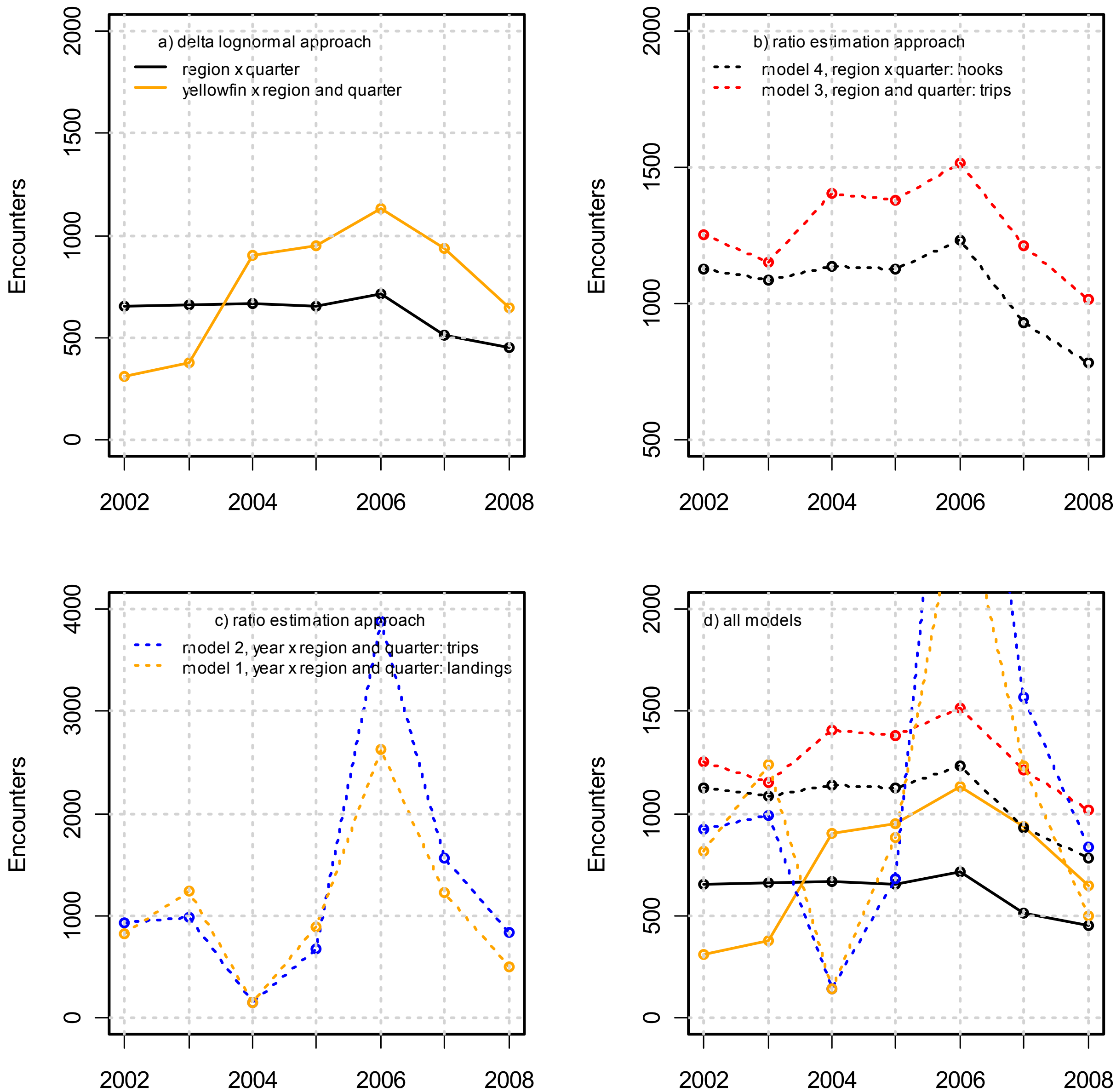


Figure 18. Relative predicted loggerhead turtle encounters from a) the delta lognormal approach with and without a targeting variable, b) the ratio estimation approach with effort as number of hooks or number of trips, c) the ratio estimation approach with effort as number of trips or as total weight of landings per trip and d) all previous models. For complete clarification of the model formulations, please consult the text.

APPENDIX A

ADDITIONAL WORK COMPLETED DURING THE FEBRUARY 2010 LOGGERHEAD TURTLE RECOVERY POTENTIAL ANALYSIS MEETING

During the loggerhead turtle RPA it was resolved that the model which best represented loggerhead turtle encounters by the longline fleet was the ratio estimation approach. It was felt that the delta-lognormal approach estimates were too conservative and not as robust.

Of the various stratification variables presented only quarter, region and yellowfin tuna catch number were used. Preference was given to using few factors with a small number of levels that could account for variance in the turtle interaction data. Therefore, the data was not stratified by year. The regions consisted only of “North” and “South” as defined above (see Figure 5) and the quarters were 2nd, 3rd and 4th. Yellowfin tuna number grouped trips according to a threshold number of yellowfin tuna caught where “Low”<20.5 and “High”>20.5. The predicted loggerhead by-catch by region, year and quarter are shown below.

Table A1. Predicted yearly loggerhead by-catch by longline fishery for a ratio estimate model stratified by yellowfin tuna catch number, region and quarter.

	2002	2003	2004	2005	2006	2007	2008	Sum
South								
Q2	78	55	165	153	115	170	171	907
Q3	390	503	1333	1385	1608	1112	770	7101
Q4	33	33	17	16	37	18	18	172
Sum	501	591	1515	1554	1760	1300	959	8180
North								
Q2	120	102	52	36	45	10	0	365
Q3	5	9	6	10	4	7	5	46
Q4	0	0	0	0	0	0	0	0
Sum	125	111	58	46	49	17	5	411

The 90% confidence limits for the estimated turtle interactions occurring in each of the strata is presented below.

Table A2. Summary statistics for ratio estimate model stratified by yellowfin tuna catch number, region and quarter.

Quarter	Region	Yellowfin Number	N*	n†	r‡	Total§	LCL**	UCL	Mean	Std
Q2	South	High	88	2	0.001	660	-4224	5543	659.8	773.49
Q2	South	Low	131	11	0.000	247	-23	518	247.4	149.38
Q2	North	High	0	0						
Q2	North	Low	31	6	0.001	366	-36	769	366.4	199.66
Q3	South	High	263	9	0.002	5143	2474	7813	5143.5	1435.44
Q3	South	Low	873	42	0.000	1958	620	3297	1958.3	795.54
Q3	North	High	2	0						
Q3	North	Low	81	11	0.000	46	-11	103	46.1	31.30
Q4	South	High	3	0						
Q4	South	Low	144	16	0.000	172	-173	516	171.7	196.50
Q4	North	High	0	0						
Q4	North	Low	16	4	0	0	0	0	0	0

Results indicate that the North encountered the majority of its turtles in the 2nd quarter in contrast to high 3rd quarter encounters in the South. Encounters in the South represented 95% of the total while 3rd quarter encounters represented 83% of the total. An association of yellowfin tuna number with encounters was observed in the South in both the 2nd and 3rd quarters when / where data was abundant. High numbers of yellowfin tuna were related to a high number of encounters in these area / times. Our best estimates of turtle encounters come from the South in the 3rd quarter and they suggest limits of between 3,000 to 11,000 encounters with an average of 7,000 over the 7 year period for an annual encounter rate of 1,000. During the meeting the annual encounter rate was gleaned from the predicted by-catch in the table above and this was calculated to be (8180+411)/7 = 1227 turtle encounters annually.

* Trips in the whole fishery
† trips in the observed fishery
‡ estimate of the ratio population mean: population total
§ number of turtle interactions
** 90% confidence limits