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ESTIMATING THE FRACTION OF WESTERN ATLANTIC BLUEFIN TUNA THAT SPAWN BY AGE FROM SIZE FREQUENCY DATA COLLECTED ON THE GULF OF MEXICO SPAWNING GROUNDS

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SUMMARY

The report of the 2017 ICCAT Bluefin Tuna Data Preparatory workshop recommended using two alternative vectors for the proportion of fish contributing to the spawning output of the population (spawning fraction) as a function of age. One vector essentially assumes that maturity alone determines contribution to the spawning stock and is similar to the vector currently used for the East Atlantic and Mediterranean (Corriero et al., 2005) where fish as young as three years old are considered to spawn effectively. The second vector was to be based on the approach of Diaz (2011), which infers spawning frequency from the age composition of fish caught on longlines in the Gulf of Mexico. It was pointed out, however, that the analysis of Diaz (2011) relied on cohort-slicing to infer age from size using a growth curve that has since been revised. Accordingly, the Data Preparatory workshop report recommended updating the Diaz (2011) oogive by using an age-length key rather than the cohort slicing approach.

RÉSUMÉ

Le rapport de la réunion de 2017 de préparation des données sur le thon rouge de l'ICCAT a recommandé l'utilisation de deux vecteurs alternatifs pour la proportion de poissons qui contribuent à la reproduction de la population (fraction de frai) comme fonction de l'âge. Un vecteur postule essentiellement que la maturité détermine à elle seule la contribution au stock reproducteur et est similaire au vecteur actuellement utilisé pour l'Atlantique Est et la Méditerranée (Corriero et al., 2005), où des poissons d'à peine trois ans sont considérés se reproduire efficacement. Le deuxième vecteur devait être fondé sur l'approche de Diaz (2011), qui déduit la fréquence de frai à partir de la composition par âge des poissons capturés à la palangre dans le golfe du Mexique. Il a été souligné, toutefois, que l'analyse de Diaz (2011) s'est appuyée sur le découpage des cohortes pour déduire l'âge à partir de la taille à l'aide d'une courbe de croissance qui a été depuis révisée. En conséquence, le rapport de la réunion de préparation des données a recommandé la mise à jour de l'ogive de Diaz (2011) à l'aide d'une clé âge-longueur plutôt que de l'approche du découpage des cohortes.

RESUMEN

El informe de la reunión de ICCAT de preparación de datos sobre atún rojo de 2017 recomendó que se utilizasen dos vectores alternativos para la proporción de peces que contribuyen a la reproducción de la población (fracción de reproductores) como una función de la edad. Un vector asume básicamente que solo la madurez determina la contribución al stock reproductor y es similar al vector utilizado actualmente para el Atlántico este y el Mediterráneo (Corriero et , 2005), en el que se considera que los peces de tan solo tres años se reproducen de un modo efectivo. El segundo vector debería basarse en el enfoque de Díaz (2011), que infiere una frecuencia de reproducción a partir de la composición por edad de los peces capturados en las pesquerías de palangre del golfo de México. Se indicó que, sin embargo, el análisis de Díaz (2011) dependía en la separación de cohortes para inferir la edad a partir de la talla utilizando una curva de crecimiento que ha sido revisada desde entonces. Por consiguiente, en el informe de la reunión de preparación de datos se recomendaba una actualización de la ojiva de Díaz utilizando una clave edad-talla en vez del enfoque de separación de cohortes.

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KEYWORDS

Spawning, size composition, long lining

Introduction

The relative number of times Atlantic bluefin tuna spawn in any given year (spawning fraction) is generally believed to increase with age, but exactly how it increases has been the subject of considerable debate. The report of the 2017 ICCAT Bluefin Tuna Data Preparatory meeting, Anon. (in press) recommended using two alternative vectors for the spawning fraction at age. The first vector is similar to that currently assumed for the East Atlantic and Mediterranean population (Corriero *et al.*, 2005), which suggests fish as young as three years old are active spawners. It essentially assumes that maturity alone determines the spawning fraction, i.e., once a fish becomes physiologically mature it will spawn the same number of times every year throughout its life. However, it was pointed out during the discussions at the workshop that recent studies of Southern Bluefin tuna suggest that older fish spawn more often as they age (Farley *et al.* 2015) and perhaps more effectively (Bravington *et al.* 2016). Therefore a second vector was proposed that was to be based on the method of Diaz (2011), which inferred spawning frequency from the age composition of fish caught on longlines in the putative Gulf of Mexico spawning grounds. This approach implicitly allows for the possibility that some fraction of younger mature fish might not migrate to the spawning ground or, if they do migrate, might not stay for as long as older fish. This paper provides an update of the size frequency approach using the latest information on the age composition of Bluefin tuna caught in the Gulf of Mexico (rather than the cohort-slicing approach employed by Diaz 2011) and suggests an alternative approach for estimating spawning fraction within the assessment model.

1. Methods

1.1 Age and size data

Age observations were available from 198 otoliths collected from the U.S. Gulf of Mexico longline fishery during 2009 through 2014. Size observations (straight fork-length) for the same period were obtained from the ICCAT data base for the U.S. and Mexican longline vessels operating in the Gulf of Mexico and nearby waters. The size composition of the ages samples, which were obtained from fish landed by U.S. longliners, is truncated somewhat compared the larger size frequency data base (**Figure 1**). Accordingly, the aged-samples were reweighted so that the relative frequency of the length composition from the 198 aged samples matched the relative frequency of the length composition for the larger sample (which was assumed to be more representative). This is procedure is analogous to applying an age-length key to the length samples. Owing to the limited number of age samples, the data were aggregated into 11 size bins: less than 190 cm, 10 cm size bins from 190 cm to 280 cm, and greater than 280 cm. The resulting age composition is shown in **Figure 2**.

1.2 Analytical approach

The number at age sampled from the GOM longline fishery (n_a) if all age classes (a) were equally vulnerable to the fishery would be some proportion q of the total abundance of the stock (N_a). Assuming that fish travel to the GOM primarily to spawn, but otherwise avoid the area, then the number at age in the sample would be

$$n_a = qN_a p_a \qquad (1)$$

where p_a is the proportion of each age class that is actively spawning. An estimate for the relative proportion spawning can be obtained from an estimate of N_a

$$p_a = \frac{n_a/(qN_a)}{MAX(n_a/(qN_a))} = \frac{n_a/N_a}{MAX(n_a/N_a)} \qquad (2)$$

where MAX denotes the maximum value over all ages. Dividing the $p_a = n_a/(qN_a)$ terms by their maximum value eliminates the nuisance parameter q. The present example uses the relative age frequency derived from the 2014 base stock assessment (Anon. 2014), but see the discussion below.

The age classes 3-8 and 16-35 were combined into plus-groups, the former owing to the paucity of samples and the latter because the assessment uses a plus-group of 16. As the values of n_a represent collections over multiple years (2009-2014), the values for N_a were taken as a weighted average of the annual estimates from the assessment, where the weights were the number of lengths sampled per year.

The "observed" values of p_a were fit using a logistic curve by weighted least squares, i.e., by finding the parameter values that minimize

$$\sum_{a=8}^{16} n_a (p_a - \hat{p}_a)^2$$

where n is the number "observed" in each age class and $\hat{p}_a$ is the expected proportion predicted using the logistic curve

$$\hat{p}_a = \frac{1}{1 + e^{-k(a-t)}}$$

For the plusgroups (3-8 and 16+) the prediction is a weighted average: for ages 3 to 8 the weights are the relative abundance of each age from the stock assessment and for 16+ the weights are the equilibrium survival to each age up to age 35 assuming a total mortality rate Z of 0.2 (as the estimate for age 16 was nearly 1.0, the results were not sensitive to the value of Z). Note that the weighted least-squares fitting method takes advantage of the observation that the binomial distribution tends to the normal distribution when there are a large number of observations. The results would likely be similar regardless of fitting method, however, and the bigger concerns are the other assumptions behind the method discussed below.

2. Results and Discussion

The fitted spawning fraction oogive for western Atlantic Bluefin Tuna is shown in **Figure 3** and **Table 1**. Mature adults under the age of 9 are estimated to spawn relatively infrequently compared with older fish and peak spawning frequency is not achieved until after age 10. A reviewer pointed out that the 2014 stock assessment for western Atlantic Bluefin Tuna relied on catch data that included fish of both eastern and western origin. To examine the sensitivity of these results to this concern, the analysis was repeated using the results from a similar assessment that used stock composition information derived from otolith chemistry to parse out eastern and western fish (Cadrin *et al.* 2017).). However, the western-only assessment actually estimated a higher number of young fish in the population than the 2014 SCRS assessment with the result that the corresponding spawning fraction oogive admits a slightly higher contribution from younger fish, but peak spawning is not reach until about 16 years of age (see **Figure 4**).

The methodology outlined above and in Diaz (2011) ultimately relies on a previous stock assessment to provide estimates of the relative abundance of each age class. However, equation (1) is essentially identical to the equation for an index of abundance except the p_a parameters would be interpreted as vulnerability (selectivity/availability) parameters and estimated from the age composition (or catch at age) data as part of the fitting process of the assessment model. In the case of the 2014 stock assessment, three of the indices of abundance used to tune the assessment model were based on the catch at age from longline fisheries in the Gulf of Mexico. The larval survey and U.S. long line CPUE vulnerability parameters were estimated from the U.S. Gulf of Mexico longline fishery CAA and the Japanese longline CPUE vulnerability parameters were estimated from catch at age derived for that fishery. If we assume as before that fish come to the Gulf of Mexico to spawn, and that the longline gear catches all size classes equally well, then the estimated relative vulnerability at age may be interpreted as the relative spawning fraction at age. The vulnerability estimates from the 2014 SCRS assessment for the U.S. and Japanese longline catch at age are consistent with those presented earlier in that they suggest a very low contribution from fish under the age of 9 and peak contributions at about age 15 (see **Figure 5**).

The estimated vulnerability coefficients from the Gulf of Mexico indices in the 2014 assessment would not be expected to be the same as those derived above because they use a longer time series of catch age that was based on cohort slicing rather than direct aging. However, given the same size and age data, the two methods should provide nearly identical results. Therefore, for 2017 I recommend using the vulnerability vectors estimated by the assessment model for the Gulf of Mexico longline fisheries as the alternative proxy for spawning fraction rather than the value in **Table 1**.

All methods based on the size composition of catches on the spawning grounds make several key assumptions:

1. the gear (here normally targeting yellowfin tuna) is nonselective
2. age and length are measured with little bias
3. the relative abundance of each age class in the overall population can be reasonably well estimated (absolute abundance is immaterial here)
4. the area fished (here Gulf of Mexico) is the primary spawning ground

In the present example the gear catches yellowfin tuna that are considerable smaller than the bluefin tuna that are caught, therefore it seem unlikely that the gear selects against small bluefin tuna. Moreover, fish under 180 cm are seldom caught in the Gulf of Mexico and surrounding waters by other gears (including recreational anglers). On the other hand, it is likely that the largest bluefin tuna are somewhat under-represented in the longline catches as they have a tendency to straighten the hooks. If true, this would imply that larger fish are proportionately even more important than estimated here.

The second assumption that age and length are measured with little bias may be problematic when cohort slicing is employed. However, the use of age-length keys should improve this situation considerably. In any case, it is unlikely that the level of bias would do much more than shift the spawning fraction curve by a year or so. The third assumption is obviously contingent on the quality of the data (and related to assumption 2) and the ability of the model to capture the essential dynamics of the population and fisheries. To the extent that a sufficiently broad scale fishery independent survey is unlike to be conducted in the near future, the stock assessment would seem to be the most viable way to characterize the age composition of the population.

The last and most vexing assumption is that the area fished (here the Gulf of Mexico and surrounding waters) corresponds to the primary spawning ground. The time period on which the oogive is based was dictated by the availability of age data, but excludes some interesting data from Cuba that may imply a higher proportion of 8 to 10 year old fish spawn off their waters (**Figure 6**). Moreover, several scientists have suggested there may be considerable spawning by even younger fish outside the Gulf of Mexico (Richardson *et al.* 2016, SCRS/2016/146). Others point out that there is presumably a reason why large fish consistently migrate to the Gulf of Mexico (perhaps higher larval survival). Further studies are needed to determine the consistency of spawning outside the Gulf of Mexico and the fate of those larvae.

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Table 1. Estimated spawning fraction oogive based on age composition data from the U.S. longline fishery in the Gulf of Mexico 2009-2014, corresponding size composition from the ICCAT data base (Mexico and U.S.) and the 2014 assessment.

Age class	*Spawning fraction*
3	0.000
4	0.000
5	0.000
6	0.001
7	0.007
8	0.039
9	0.186
10	0.563
11	0.879
12	0.976
13	0.996
14	0.999
15	1.000
16	1.000
17	1.000
18	1.000
19	1.000
20	1.000

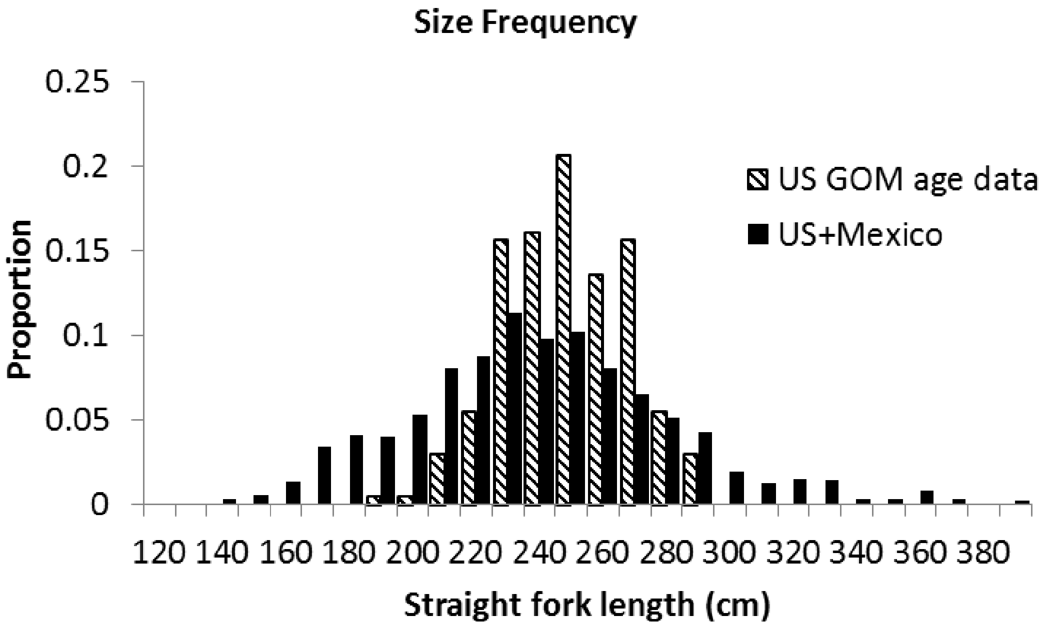

Figure 1. Size frequency of aged samples (stippled bars) compared with the size frequency of combined US and Mexico long line samples in the ICCAT data base.

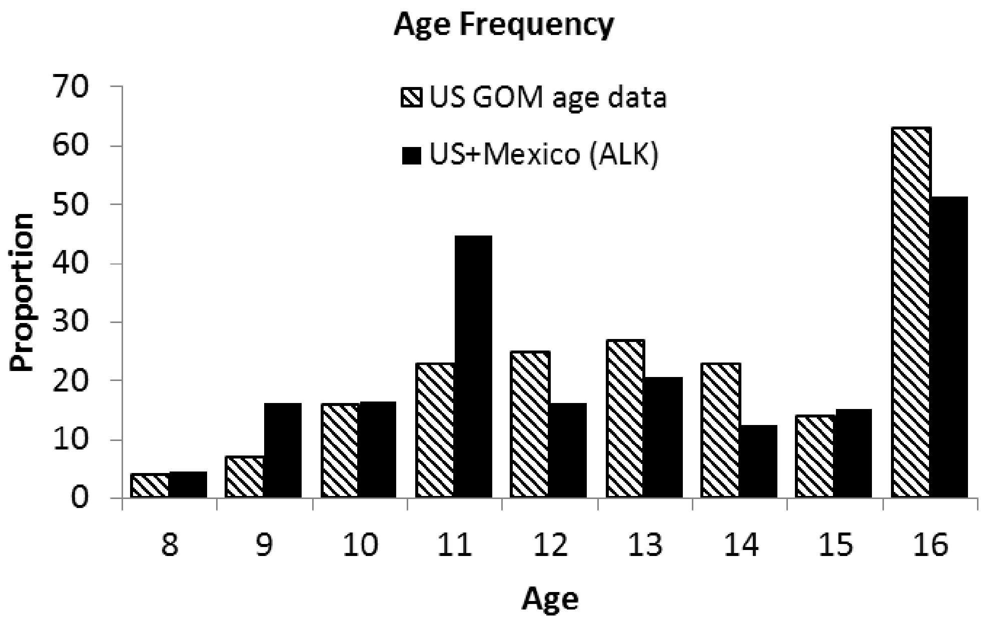

Figure 2. Age frequency of aged samples (stippled bars) compared with the age frequency of combined US and Mexico long line samples in the ICCAT data base (obtained by the reweighting procedure). The bar for age 8 represents ages 8 or younger and the bar for age 16 represents ages 16 and older.

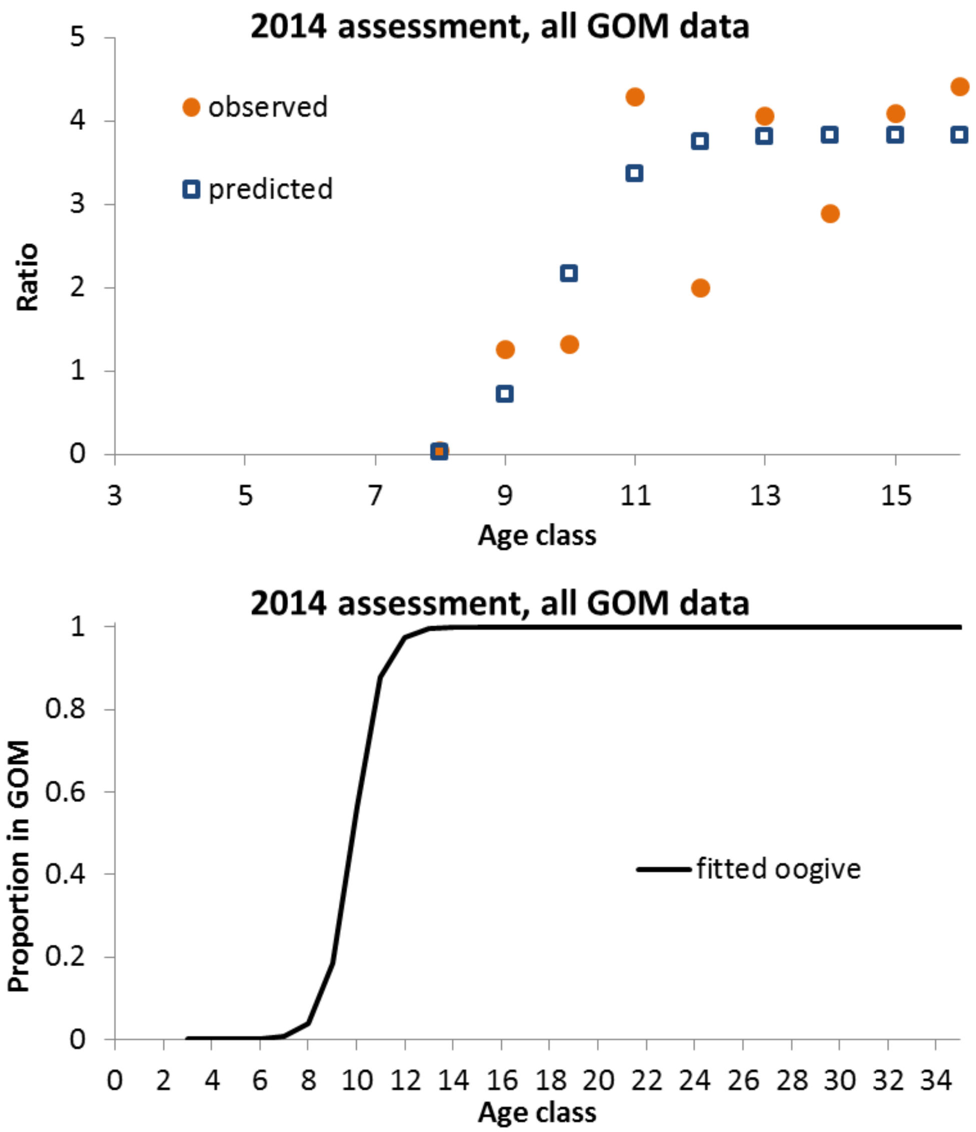

Figure 3. Observed and predicted ratios following equation 2 (top graph) and corresponding model prediction for the spawning fraction oogive (bottom graph) based on estimates of abundance from the 2014 stock assessment.

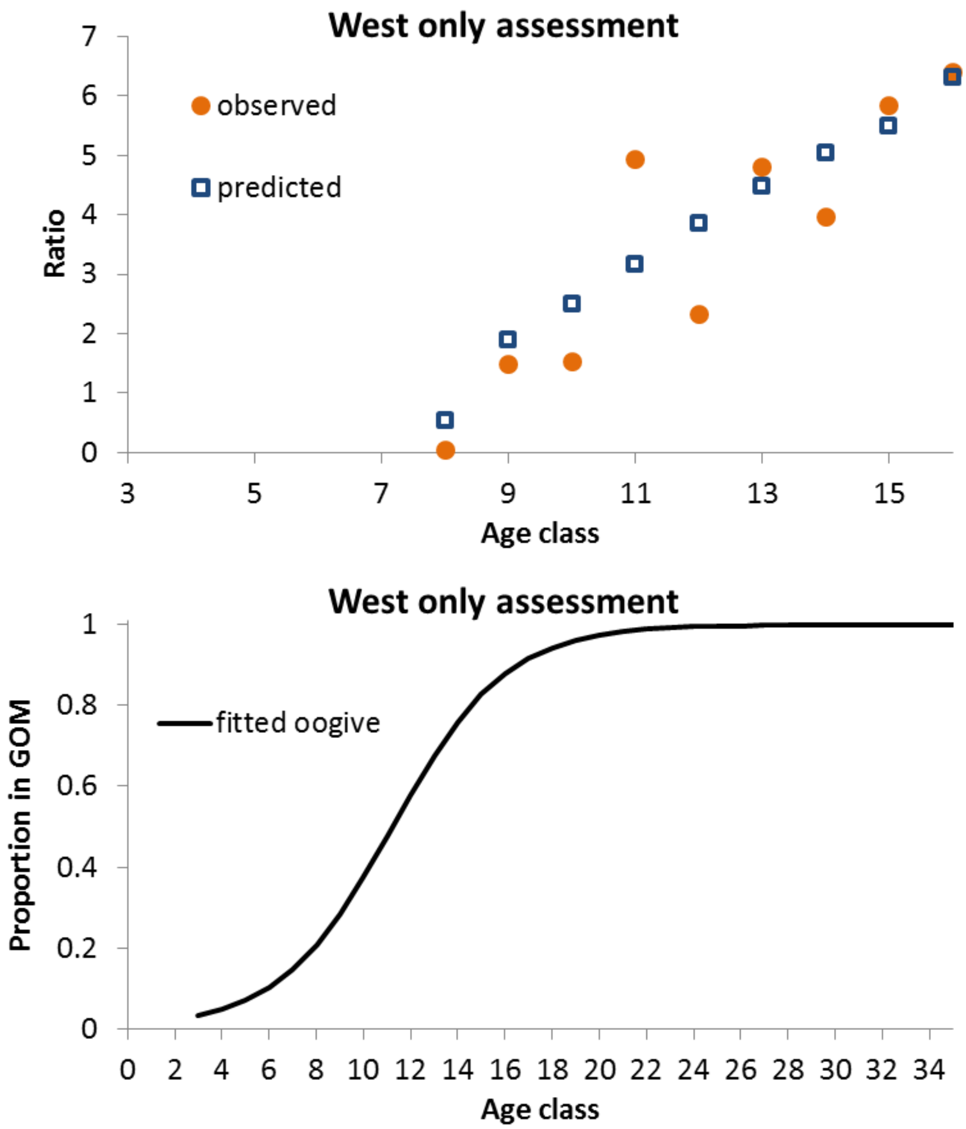

Figure 4. Observed and predicted ratios following equation 2 (top graph) and corresponding model prediction for the spawning fraction oogive (bottom graph) based on estimates of abundance from the "western only" assessment of Cadrin *et al.* 2017.

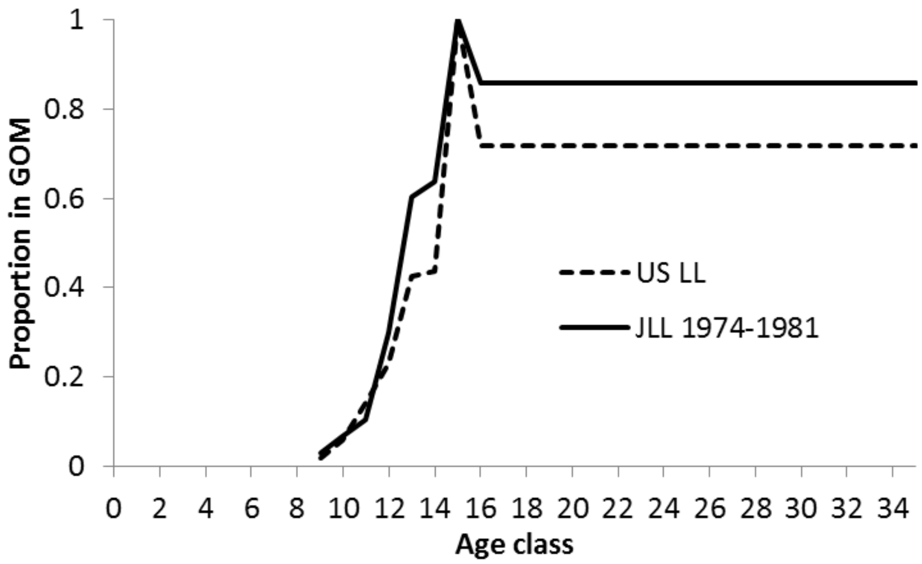

Figure 5. Spawning fraction oogive (bottom graph) based from the vulnerability vectors estimated by the 2014 SCRS assessment from U.S. (dashed line) and Japanese (solid line) longline catches in the Gulf of Mexico.

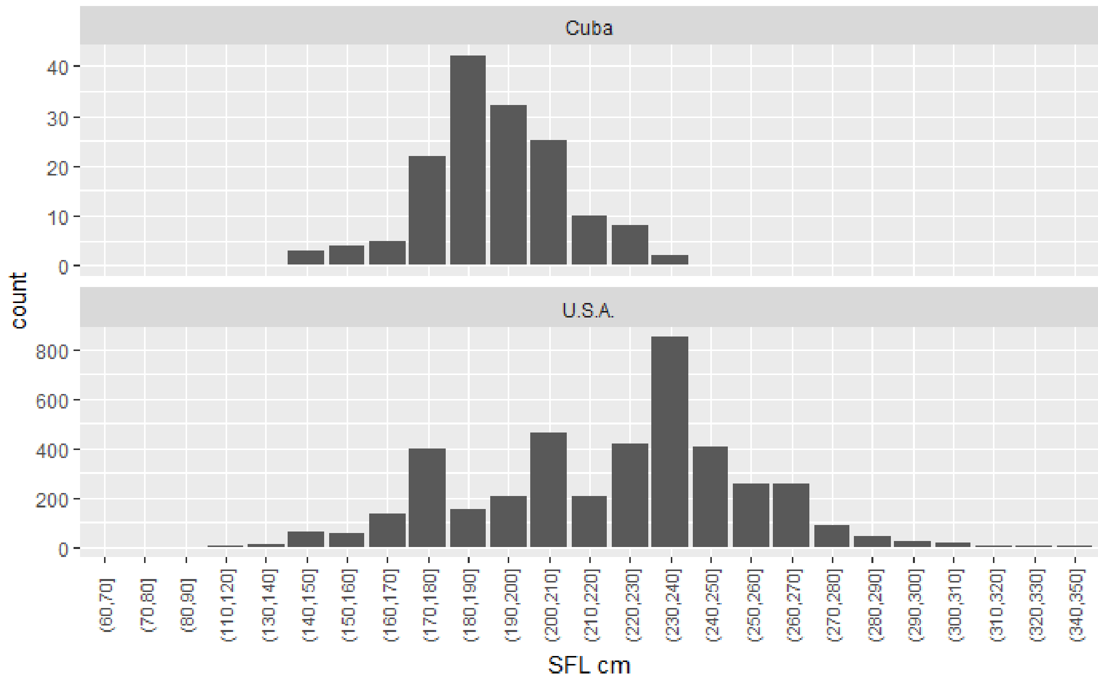

Figure 6. Task II size data from the Gulf of Mexico (BF60, LL, SFL, 10 cm bins) for the US (back to 1984) and Cuba (2002), showing a higher frequency of fish below 180 cm than the 2009 to 2014 time frame used in the analysis