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LENGTH BASED INDICATORS OF ATLANTIC SWORDFISH AND BLUEFIN TUNA STOCK STATUS

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SUMMARY

Rebuilding and maintaining healthy spawning stocks can be facilitated by being conscious of how fishery removals affect a stock's age composition. Length based indicators for the fraction of the catch that are mega spawners, mature and of optimal size for harvest are shown to be a useful diagnostic tool that provides an additional perspective on stock status and that can identify fishing in regions and/or with gears that put the population at risk. A method to standardize the estimation of these indicators that accounts for the total removal by fleet is applied to the North and South swordfish and East and West bluefin tuna stocks.

RÉSUMÉ

Le rétablissement et le maintien des stocks reproducteurs en bonne santé peuvent être facilités si l'on sait comment les prises affectent la composition démographique d'un stock. Les indicateurs reposant sur la taille de la fraction de la capture de spécimens de méga-reproducteurs, matures et de taille optimale pour la capture se sont avérés être un outil diagnostic utile fournissant une perspective supplémentaire de l'état du stock et servant à identifier la pêche dans les régions et/ou au moyen d'engins mettant la population en péril. Une méthode de standardisation de l'estimation de ces indicateurs tenant compte de la ponction totale par flottille est appliquée aux stocks d'espadon du Nord et du Sud et de thon rouge de l'Est et de l'Ouest.

RESUMEN

Recuperar y mantener stocks reproductores saludables puede facilitarse siendo conscientes de cómo las extracciones de una pesquería afectan a la composición por edades del stock. Los indicadores basados en la talla para la parte de la captura que son mega reproductores, maduros y de talla óptima para la captura demuestran ser un herramienta de diagnóstico útil que proporciona una perspectiva adicional sobre el estado del stock y que puede identificar pesca en regiones y/o con artes que ponen la población en riesgo. Un método para estandarizar la estimación de estos indicadores que tiene en cuenta la extracción total por flota se aplica a los stocks de pez espada del norte y del sur y de atún rojo del este y del oeste.

KEYWORDS

Length based indicators, Swordfish, Bluefin tuna, Resource management

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Introduction

Sensible fisheries management should include as a target to let all (100%) fish spawn before being caught (i.e., zero catch of juveniles) and to avoid harvesting large mega spawners while attempting to harvest individuals near the size providing maximum yield (Froese 2004). The degree to which this is occurring in the North, South and Mediterranean Swordfish fisheries, Eastern and Western and Southern Bluefin tuna fisheries (**Figure 1**) is considered by examining the trends in 3 key length based indicators linked to the optimal length of harvest, length at 50% maturation and maximum length. Trends within each stock area are disaggregated by Flag and gear to understand which Flag and or gear is fishing optimally. A standardized approach is provided that controls for the bias in sampling and the relative magnitude of removals by fleet.

Methods

Task II size data

The size samples were extracted from ICCAT's Task II data at http://iccat.int/en/accesingdb.htm. The sizes were found in t2sz_20131210web.mdb [MS Access; version 11/2016, 11 Mb (rar)] and the catch/effort statistics in t2ce_20151102web.mdb [MS Access; version Nov 2013, 32 Mb (rar)]. An update to these data (rev 4) that is not generally available for download was also used.

In the Task II table the length and weight of a fish was expressed in several formats thus it was necessary to transform samples to a common format. Swordfish eye fork length was converted to lower jaw fork length using:

$$LJFL = 7.821534 + 1.089696 * \text{EFL} \text{ (Rey and Garcés 1979)},$$

and Bluefin tuna curved fork length was transformed to straight fork length using:

$$SFL = 1.85746 + 0.9606 * CFL \text{ (Rodriguez-Marin 2015)}.$$

It was also assumed that TL, FL and WGT-FL were all synonyms for SFL.

Life History Parameters

The life history parameters used were based on values provided by Fishbase.org (Froese and Pauly 2012) and are summarized in **Table 1**. The length at optimum yield, L_{opt}**,** was calculated using estimates of *K*, L_∞ and *M* (Beverton 1992) as:

$$L_{opt} = L_\infty \left(\frac{3}{\left(3 + \frac{M}{K}\right)} \right)$$

L_{mat} indicates length at first maturity and L_{max} is the maximum size reached during that time (Froese and Binohlan 2010). In the case of Swordfish, the lower bound of L_{mat} for females was used while for Atlantic Bluefin tuna the growth characteristics of the western Atlantic catches was used and a length a maturity consistent with eastern catches.

Length Based Indicators

Following Froese 2004, P_{mat} is defined as the percentage of mature specimens in the catch. Mature individuals are defined as those which have had a chance to spawn at least once. P_{opt} is the percentage of fish caught within +/- 10% of optimum length and the target for harvesters is to have the entire catch within this interval (**Figure 2**). The optimum length occurs where the number of fish in a given unfished year class multiplied by their mean individual weight is highest, resulting in maximum yield/revenue. Optimum length is typically a bit larger than length at first maturity and can be easily obtained from growth and mortality parameters or empirical equations (Froese and Binohlan 2000). P_{mega} is the percentage of old, large fish (mega-spawners) in the catch (between optimum length plus 10% and the maximum length). The target is to harvest no (0%) mega-spawners. If the catch reflects the age and size structure of the stock, however, 30-40% of mega-spawners in the catch would likely reflect a healthy population; 20% of mega-spawners would be cause for concern and should be the lower limit. There are numerous examples of why large and older fish play an important role in the long-term survival of a population (Froese 2004).

R Functions for calculating these indicators are provided in the Appendix.

Weighted estimates for Length Based Indicators

Annual time series of the nominal estimates of P_{mat}, $P_{opt,}$ and P_{mega} make no allowance for the gear, flag or area contributing the catch at size data in a given year or size of the sample. Neither is any consideration given for the scale of the impact a given fleet has on the stock. Consequently, standardized annual estimates weighted by the catch fraction were calculated for each indicator as follows:

1. P_{mat}, $P_{opt,}$ and P_{mega} were calculated for each Stock, Year, Month, Flag, Gear, Area combination using revision 4 of the Task II data. Not all Gears or Flags were represented however, due to a low number of samples. The north Atlantic stock included LL, RR, HP and GN while in the south only LL and GN. Flags with less than 50 samples over the entire 45 year time series were excluded.

2. Separate weighted GAMs were fit to each indicator and stock. The models for Swordfish were all of the same form and included a smoother for Year within each Area and parametric Gear, Flag, Gear:Area and Flag:Area effects all weighted by the sample size. The models for Bluefin tuna included a smoother for Year and parametric Gear, Flag and Gear:Area effects all weighted by the sample size. A beta distribution of the data was assumed for all models.

3. Estimating the year effect for each indicator involved averaging the values of P_{mat}, $P_{opt,}$ and P_{mega} over a consistent grid of factor levels in each year. The grid preserved the nested aspect of the factors so that estimates for each fleet (gear-flag combination) were only calculated for the areas where a given fleet had provided samples over the 45 year time series. For example, for Canada, P_{mat}, $P_{opt,}$ and P_{mega} were estimated in each year for LL, RR, HP and GN in each of the 2 areas that produced size samples and nowhere else.

4. The grid estimates for a given indicator were averaged over the areas within each year/flag/gear combination. Averaging over areas allowed 1:1 linking with the Task I landings data which is used to weight the estimates of P_{mat}, $P_{opt,}$ and $P_{mega.}$ This step was necessary because the Task I landings has significant catch that is attributed to unidentified areas.

5. The annual weighted average of P_{mat}, $P_{opt,}$ and P_{mega} was calculated where the weights were the fraction of the annual Task I landings that a given gear/flag accounted for. Due to the requirement for a 1:1 link between the Task II based indicator estimate and the Task I based weight, the weighted average did not include any indicator estimates from the model that did not have a corresponding catch in the Task I weight and vice versa. The weighted mean and variance:

$$\mu = \sum_{i=1}^{N} p_i x_i \ \ and \ \ \sigma^2 = \sum_{i,j=1}^{N} p_i p_j \, Cov(x_i, x_j)$$

Results

Nominal trends in P_{opt}, P_{mat} and P_{mega} are provided for Swordfish by stock area (**Figure 3**), by Flag within stock area (**Figure 4 and Figure 5**) and by Gear group within stock area (**Figure 5 and Figure 7**). Similarly, trends in P_{opt}, P_{mat} and P_{mega} are also provided for Atlantic Bluefin tuna and Southern Bluefin tuna by stock area (**Figure 8** and **Figure 11**), by Flag within stock area (**Figure 9** and **Figure 12**) and by Gear group within stock area (**Figure 11** and **Figure 13**).

The standardized, landings weighted trends in P_{mat}, $P_{opt,}$ and P_{mega} for southern and northern Swordfish stocks are shown in **Figure 14.** All standardized indicators have similar trends to their nominal counterparts except that the standardized values at the beginning of the series are higher than current values whereas the nominal values at the two extremes are more similar to each other. Improvement in the catch composition begins in 1990 for the northern stock and around 2000 for the southern stock, especially with respect to the proportion of fish larger than $L_{mat.}$

Figure 15 provides the standardized, landings weighted trends in P_{mat}, $P_{opt,}$ and P_{mega} for western and eastern Bluefin tuna stocks. All standardized indicators for the western stock show an improvement in the proportion of mature sized fish in the catch, the proportion of large spawners and the proportion caught at $L_{opt.}$ Though the indicators for eastern stock show improvement, the overall level is lower than the western stock in all cases.

Summary

1. The nominal trends in P_{opt}, P_{mat} and P_{mega} by stock area and for gear groups and Flags within stock areas are informative but given possible regional differences in the availability of all age components of a stock to the gear, regional differences in the gears used and differences in each Flag's share of the global TAC and allocation of this TAC to its gear groups, weighting of the Gear-Flag samples and standardization for sampling differences is necessary to provide improved indicator estimates and interpretation of stock status.

2. If there are no upper limits on the size of Swordfish caught and L_{max} and L_{opt} have been specified correctly, then the lack of mega spawners is a concern for all stocks. Pmega is showing some increase for the north and south stocks but is still well below 1970 values. The harvesting of juveniles is a concern for all stocks with the Mediterranean in the greatest jeopardy and consequently Popt also performs poorly. Current trends in for the Mediterranean and North Atlantic stocks are positive and should be evaluated against changes in the fishery.

3. Standardized and weighted estimates of Popt and Pmat for both Swordfish stocks indicate that over the past 15 years, an increasing fraction of the catch is greater than Lmat, though the trend for Popt is less optimistic. A very low proportion of mega spawners is of concern if there has been no effort to avoid them. Alternatively, a low occurrence may be symptomatic of a poorly estimate value for Lopt.

4. Trends in the standardized and weighted indicators for Bluefin tuna differed between stocks. The western stock has had a fairly large fraction of the catch above the length of maturity whereas in the eastern stock the fraction above Lmat has only been increasing recently (since ~1995). Mega spawners rarely appear in the eastern catch while they represent 25% of the western catch. This discrepancy could be the result of a genuine absence of large spawners or caused by centuries of exploitation. Some consideration should be given to the fact that eastern and western stocks mix on the eastern, central and western Atlantic fishing grounds and that recent evidence indicated an increasing proportion of young migrants from the east in the western catch.

5. The situation for Southern Bluefin tuna appears very positive with all indicators moving in the right direction.

6. Disaggregating the Swordfish and Bluefin tuna catch by Flag within a management unit shows differences in the trends of the indicators that could be a function of fishing practices or regional differences in the availability of all age components of the stock. Disaggregating the catch by gear group provides insight into which gears fish optimally but, given that use of some gears can be localized, interpretation requires a good understanding of the fishery.

References

Beverton, R. J. H. (1992). Patterns of reproductive strategy parameters in some marine teleost fishes. J. Fish Biol. 41(Suppl. B), 137-160.

Froese, R. 2004. Keep it simple: three indicators to deal with overfishing. Fish and Fisheries 5:529 86-91.

Froese, R., and D. Pauly. 2012. FishBase. World Wide Web electronic publication: www.fishbase.org.

Froese, R., and C. Binohlan. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology 56:758-773.

Rey J.C., A. González Garcés (1979). Nuevos datos sobre la pesquería española de pez espada, *Xiphias gladius*, biología y morfometría. Col.Vol.Sci.Pap. ICCAT, 8 (1): 504-509.

Rodriguez-Marin E, Ortiz M, Ortiz de Urbina J.M., Quelle P, Walter J, Abid N, et al. 2015. Atlantic bluefin tuna (*Thunnus thynnus*) Biometrics and Condition. PLoS ONE 10(10): e0141478.doi:10.1371/journal.pone.0141478

Table 1. Life history parameters used in deriving P_{opt}, P_{mat} and P_{mega} for Swordfish, Atlantic bluefin tuna and Southern bluefin tuna.

Species	L_{max}	L_{mat}	L_{∞}	t_0	K	L_{opt}	M
SBF	245	119	220	NA	0.15	143.5	0.24
BFT	295	100	263.77	-0.67	0.26	223.6	0.14
SWO	335.5	156	337.21	-2.81	0.115	213.5	0.2

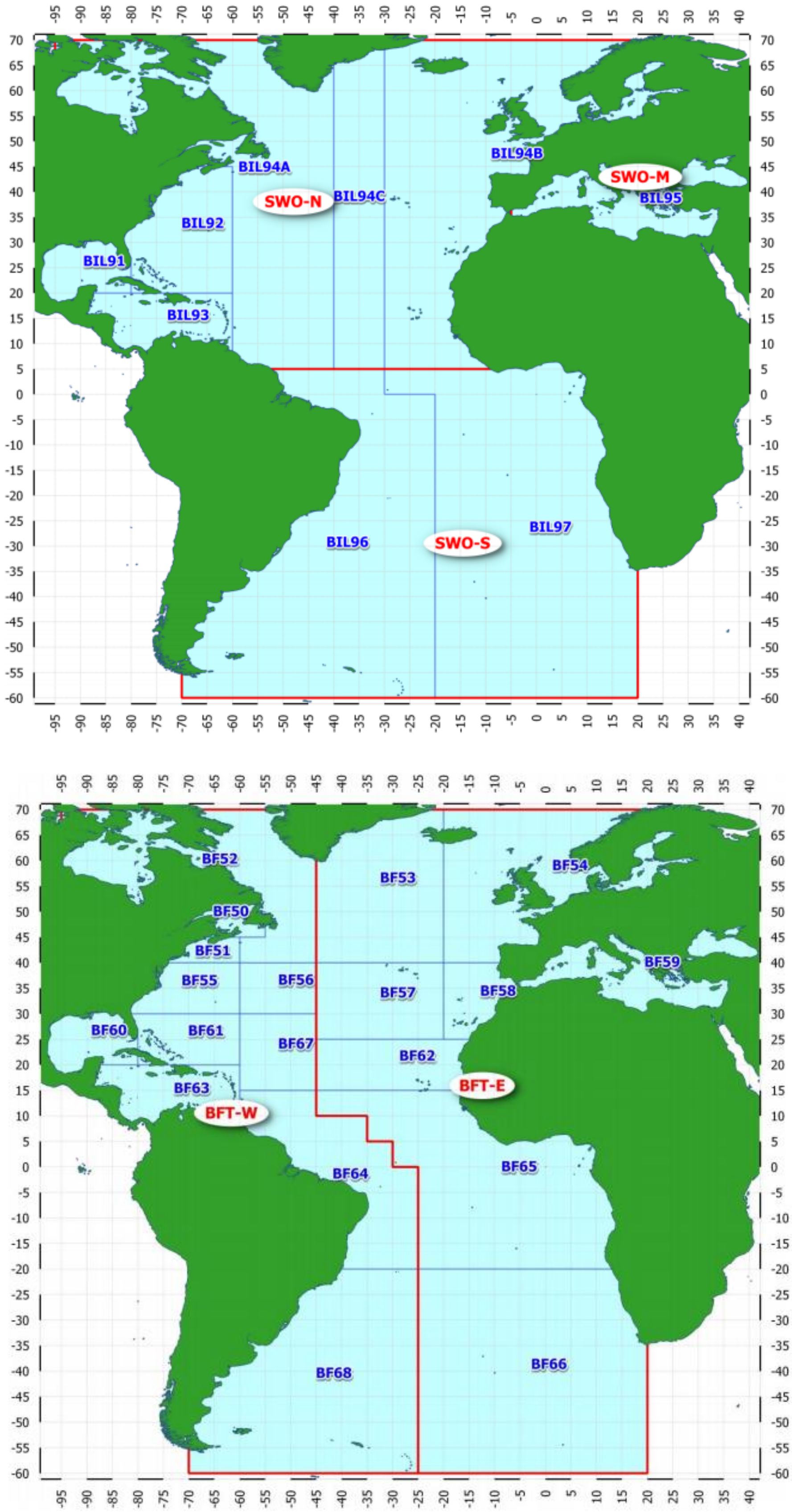

Figure 1. ICCAT Swordfish (top) and Bluefin tuna (bottom) sampling areas (BIL91 to BIL97) within each stock /statistical area (SWO-N, SWO-S and SWO-M). (Version: 2016.02 EN).

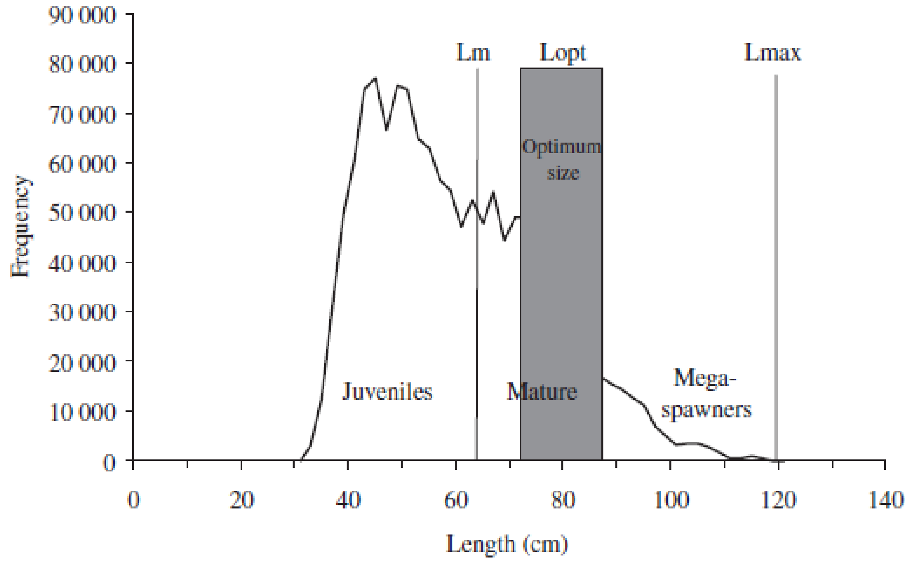

Figure 2. Length at first maturity (L_{mat}), length range where maximum yield could be obtained (L_{opt}), and the maximum length reached (L_{max}) for a population of cod (Froese 2004).

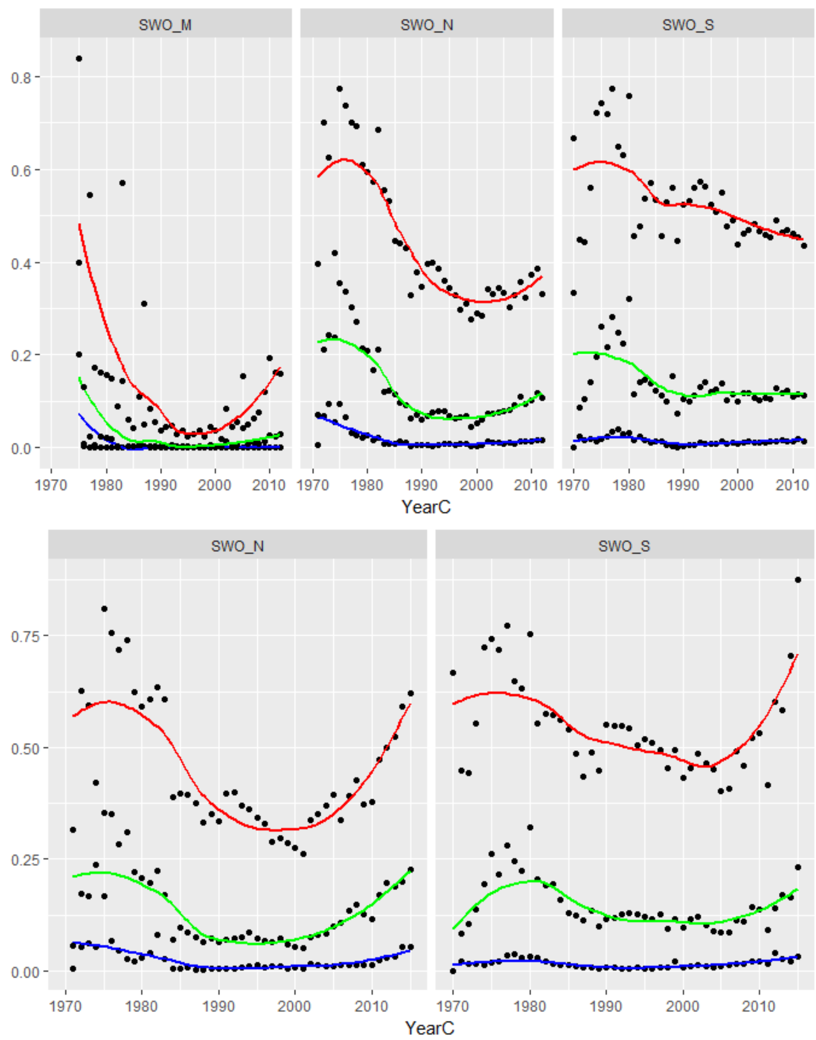

Figure 3. Length based indicators for Swordfish caught within the Mediterranean, North Atlantic and South Atlantic stock areas. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Top panel uses Task II size revision 3 data while the bottom plot uses Task II size revision 4 data.

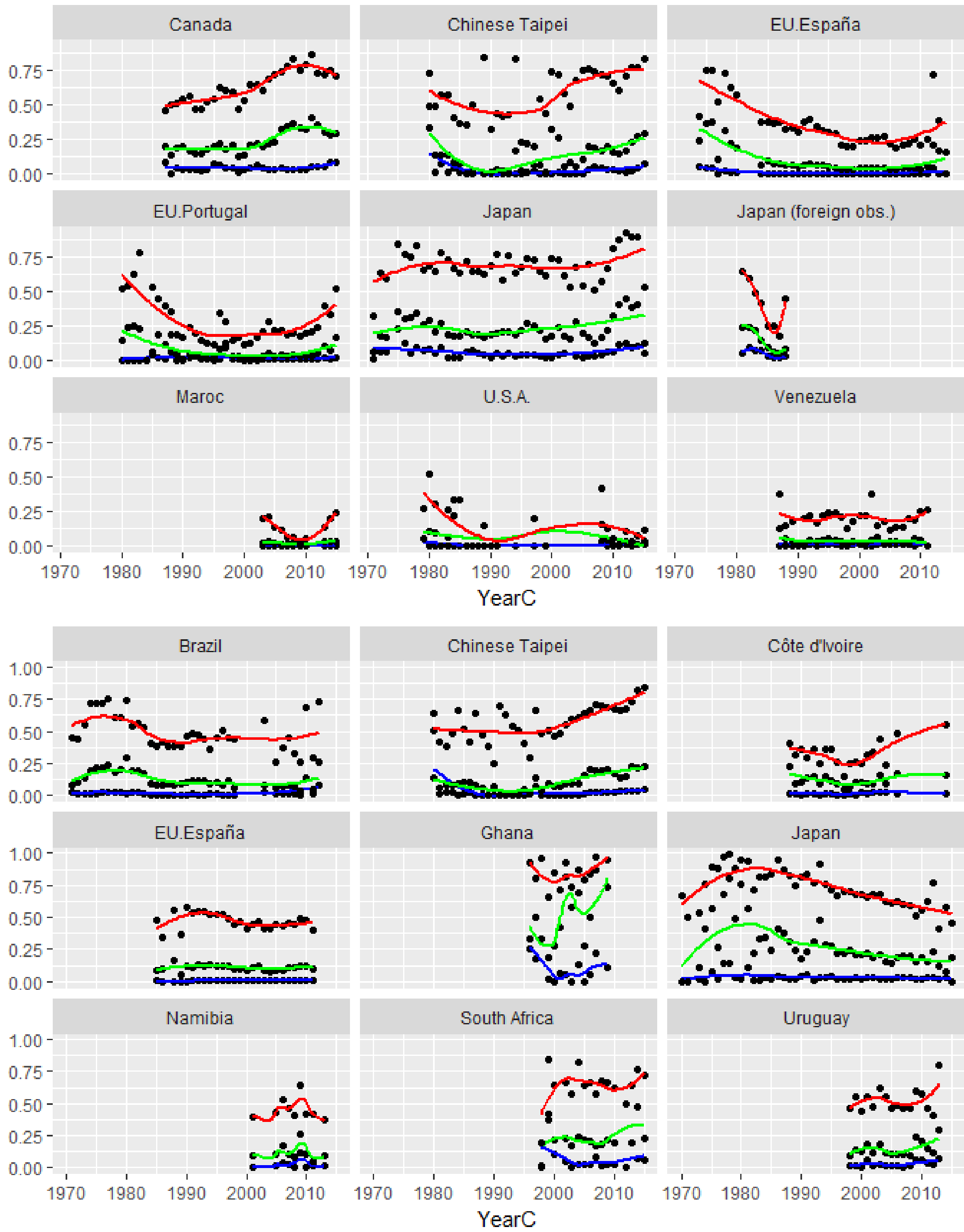

Figure 4. Length based indicators by Flag for Swordfish caught in the North Atlantic (top) and South Atlantic (bottom) stock areas. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Task II size revision 4

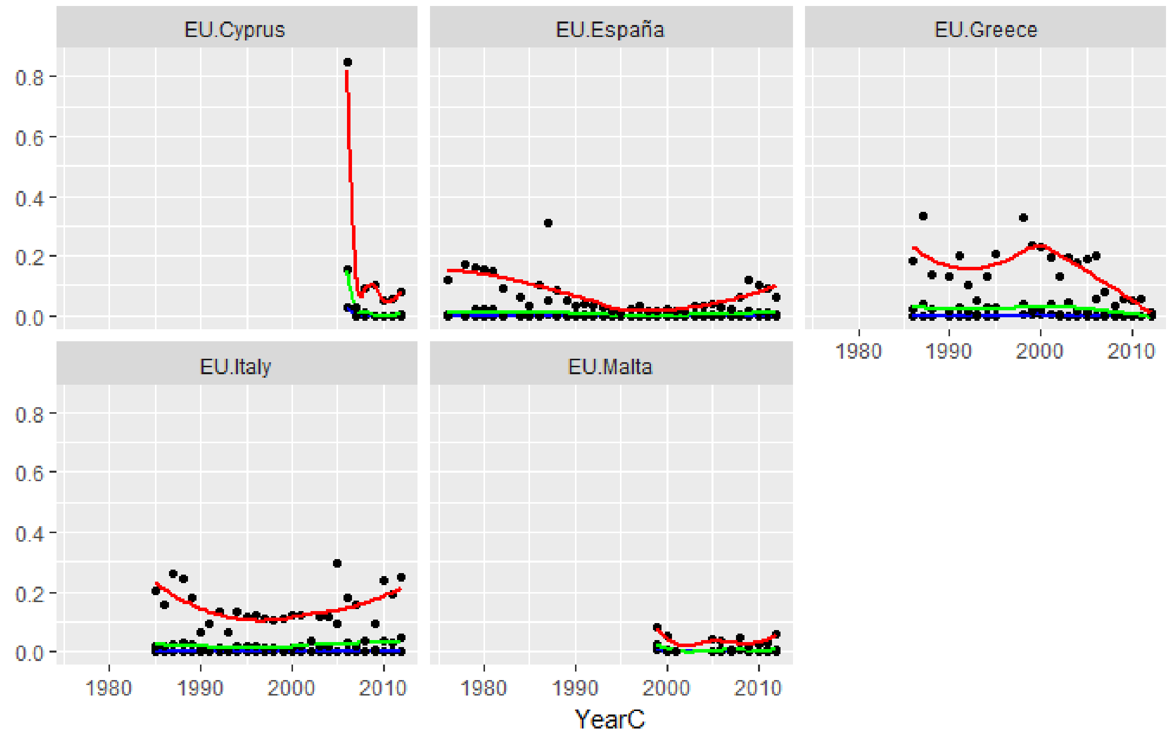

Figure 5. Length based indicators by Flag for Swordfish caught within the Mediterranean stock area. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Task II size revision 3

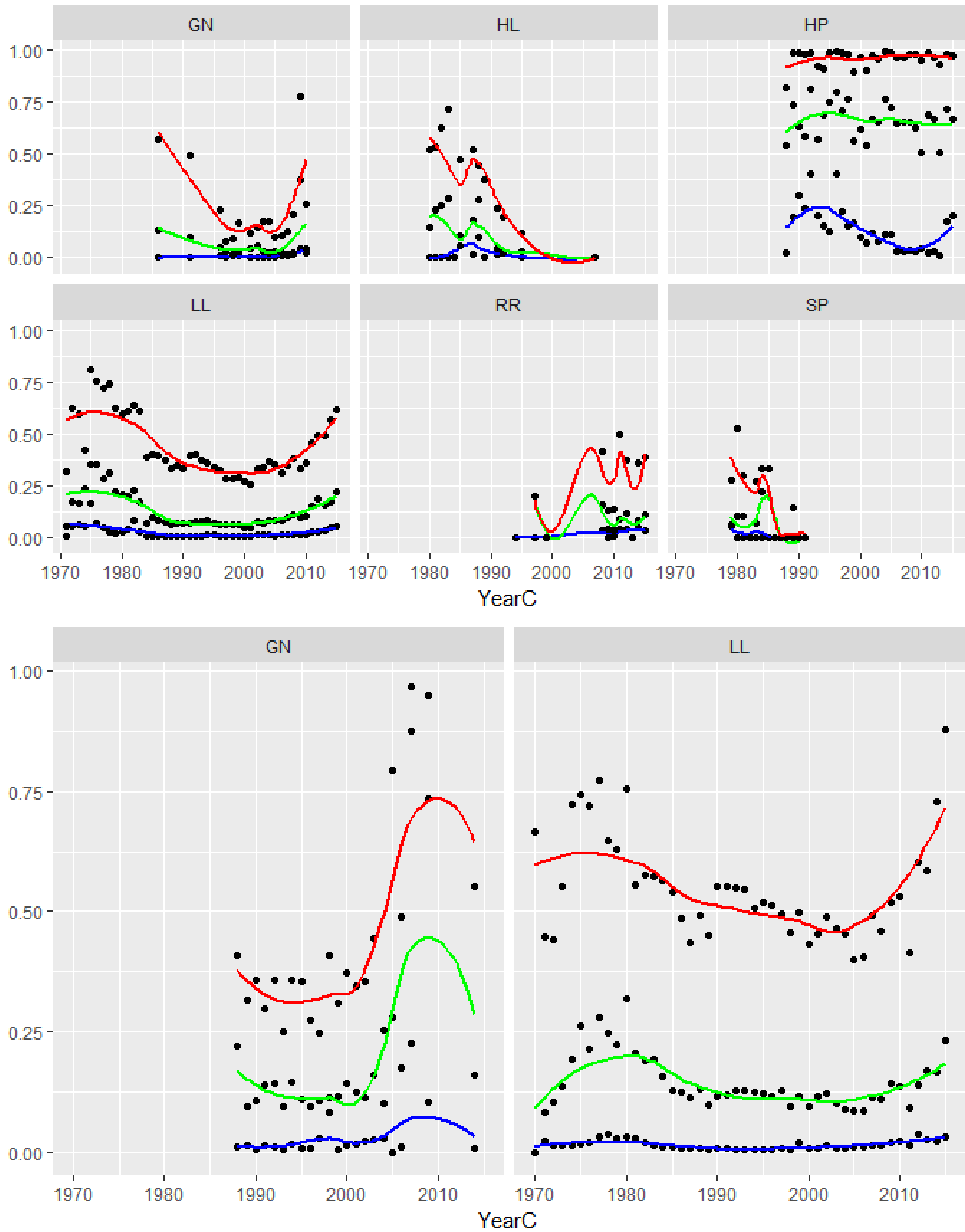

Figure 6. Length based indicators by Gear group for Swordfish caught in the North Atlantic (top) and South Atlantic (bottom) stock areas. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Task II size revision 4

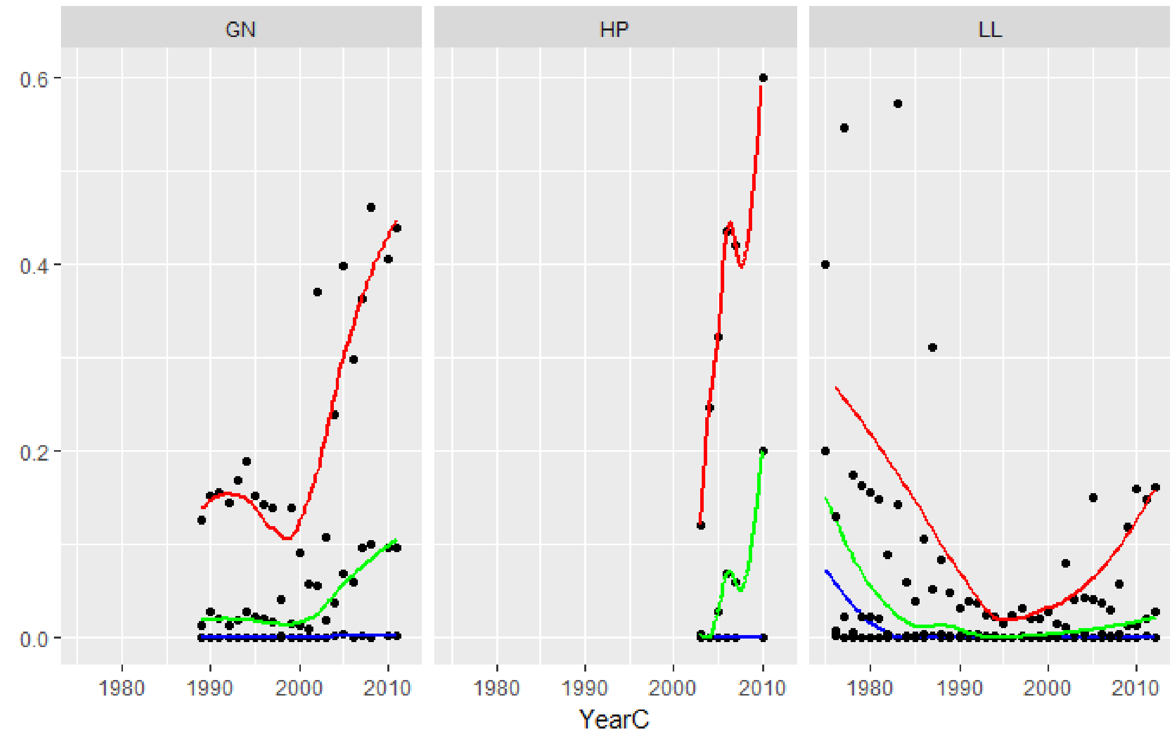

Figure 7. Length based indicators by Gear group for Swordfish caught within the Mediterranean stock area. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Task II size revision 3

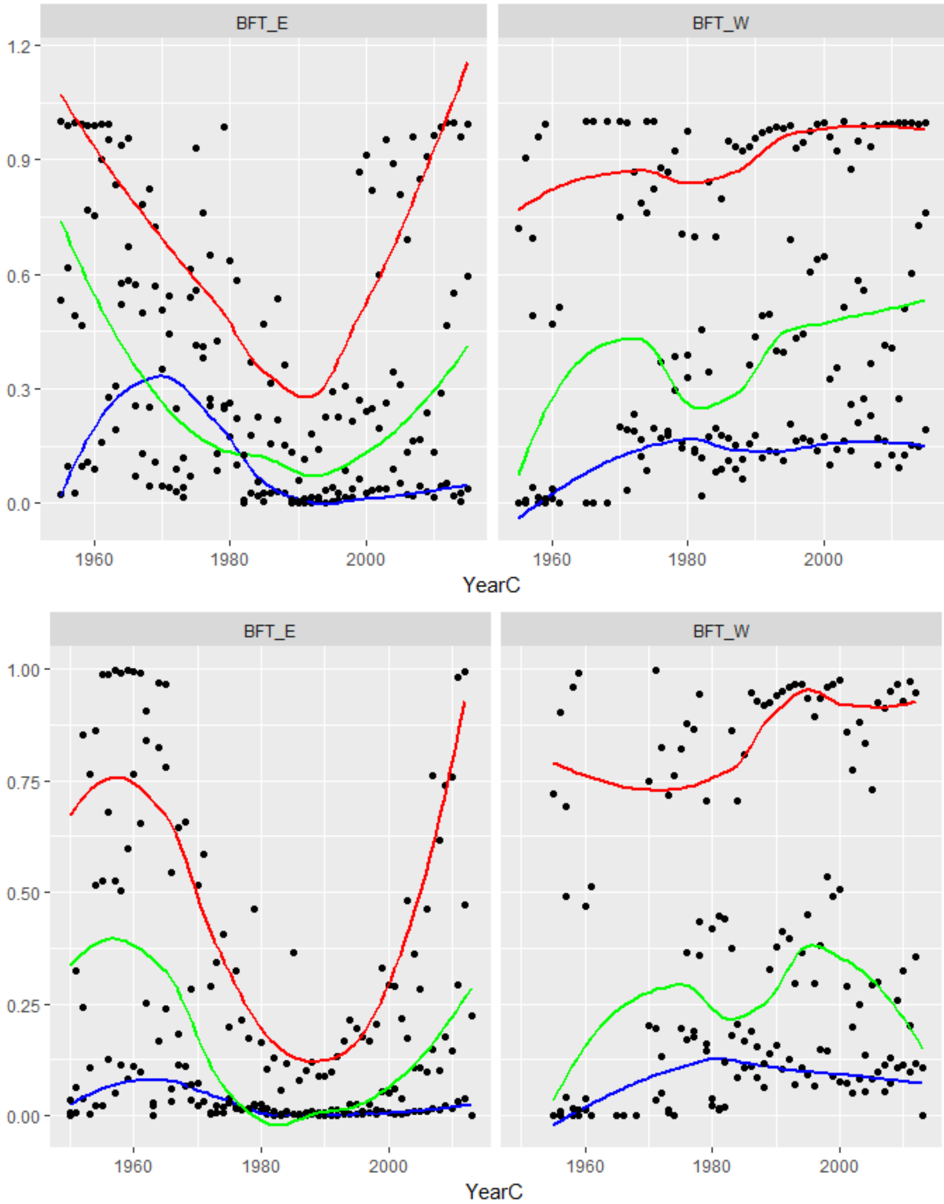

Figure 8. Length based indicators for eastern and western Atlantic Bluefin tuna caught within the eastern and western Atlantic stock areas. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Top panel uses Task II size revision 4 data while the bottom plot uses Task II size revision 3 data.

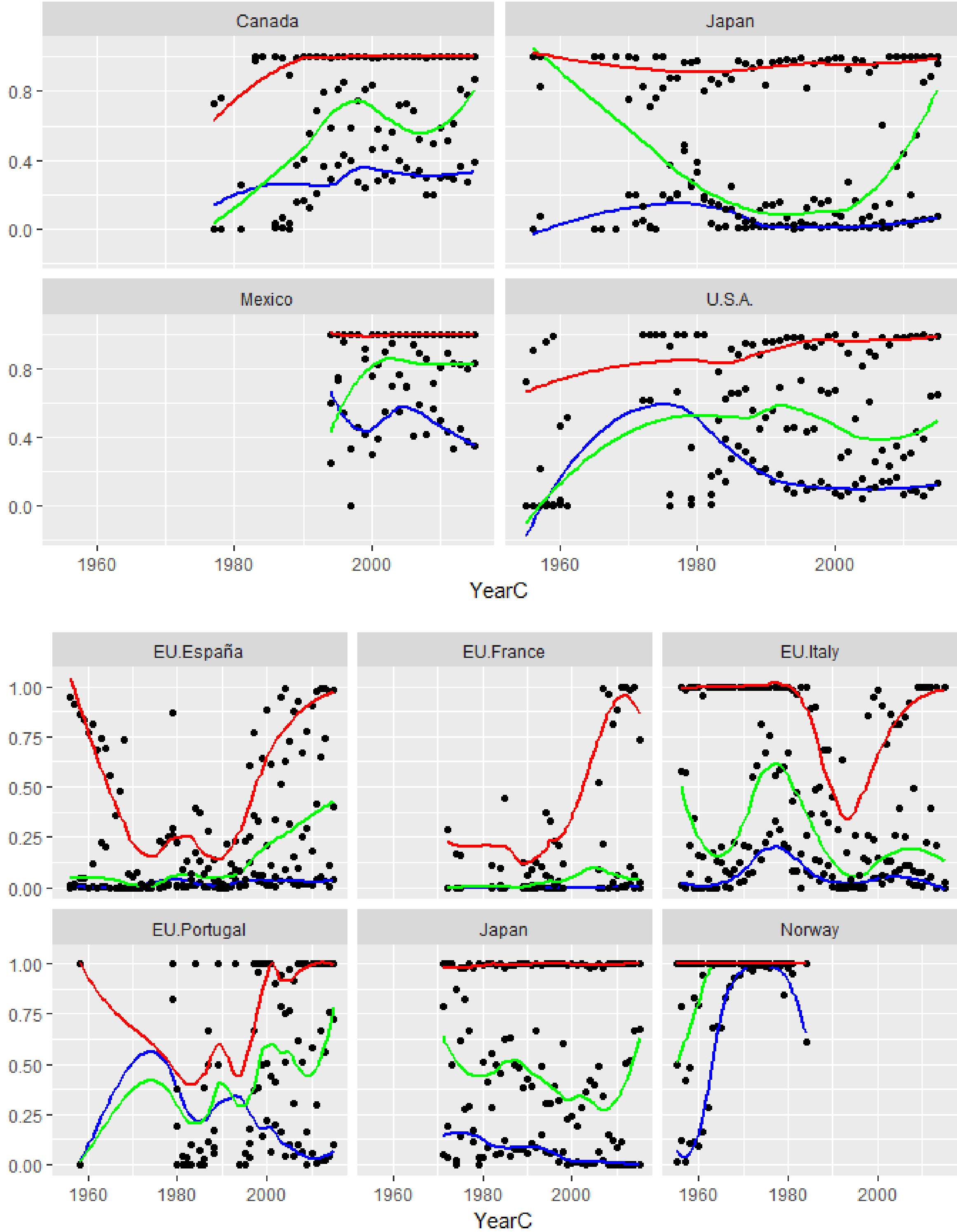

Figure 9. Length based indicators by Flag for Atlantic Bluefin tuna caught within the western (top) and eastern (bottom) Atlantic stock areas. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Task II size revision 4 data.

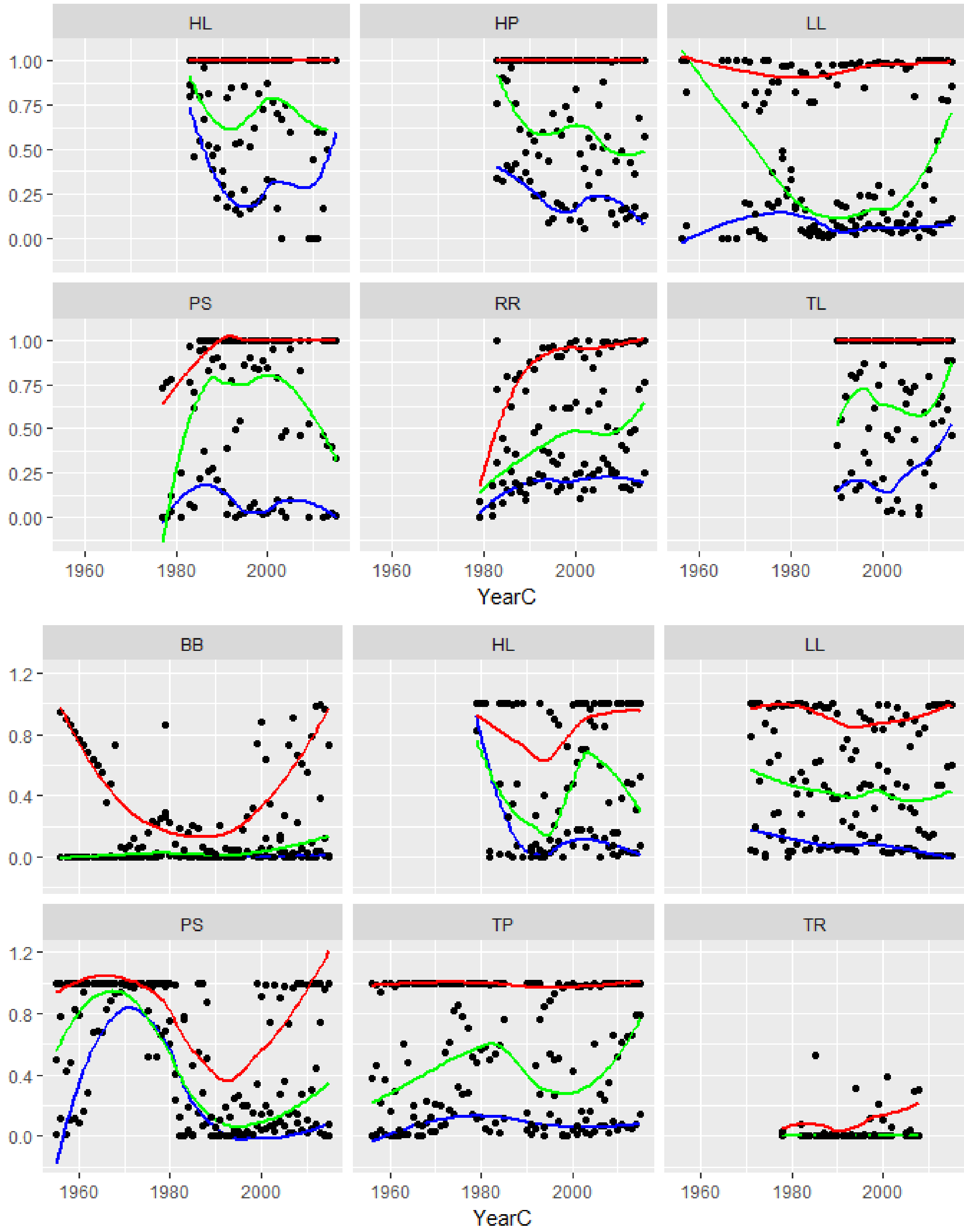

Figure 10. Length based indicators by Gear group for Atlantic Bluefin tuna caught within the western (top) and eastern (bottom) Atlantic stock areas. P_{opt} (green), P_{mat} (red) and P_{mega} (blue). Task II size revision 4 data.

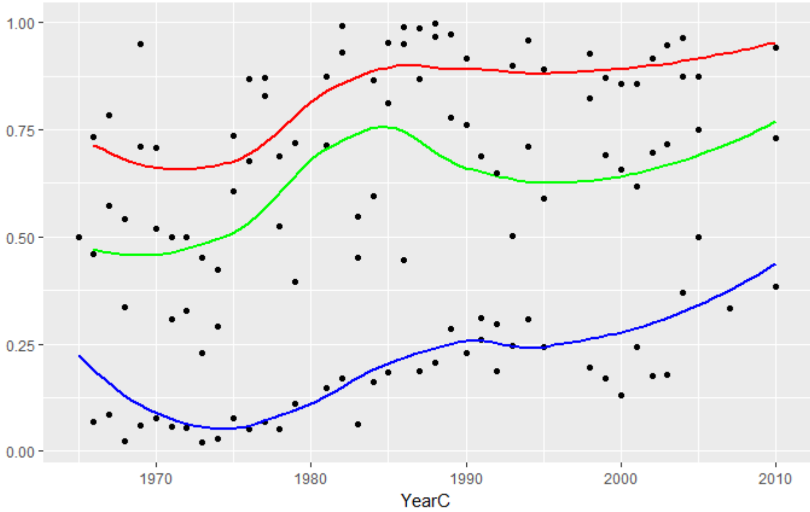

Figure 11. Length based indicators for southern Atlantic Bluefin tuna caught within the south Atlantic. P_{opt} (green), P_{mat} (red) and P_{mega} (blue).

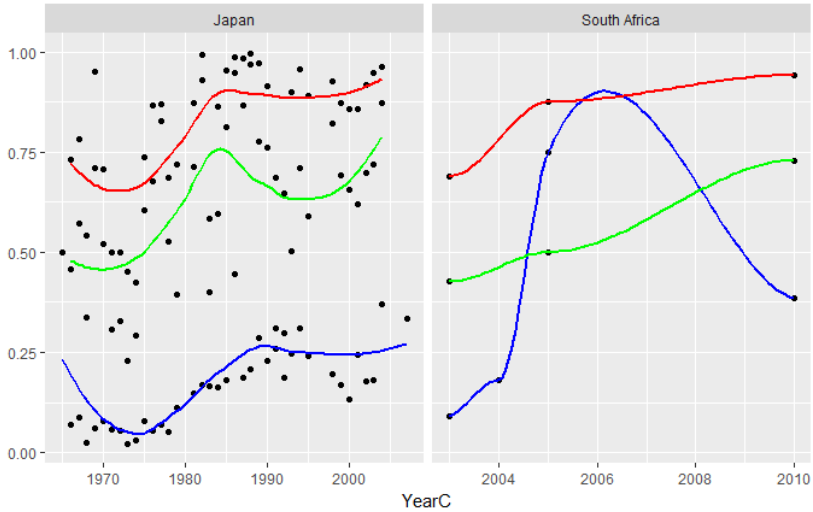

Figure 12. Length based indicators by Flag for Southern Atlantic Bluefin tuna caught within the south Atlantic. P_{opt} (green), P_{mat} (red) and P_{mega} (blue).

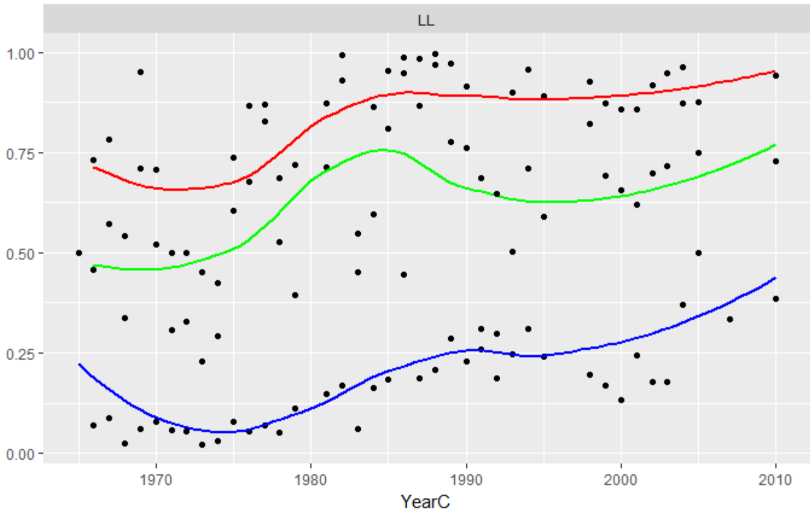

Figure 13. Length based indicators for Southern Atlantic Bluefin tuna caught within the south Atlantic using lon line gear. P_{opt} (green), P_{mat} (red) and P_{mega} (blue).

Figure 14. Length based indicators for Swordfish caught within the North Atlantic (top) and South Atlantic stock areas (bottom). Popt (green), Pmat (red) and Pmega (blue). Task II size revision 4

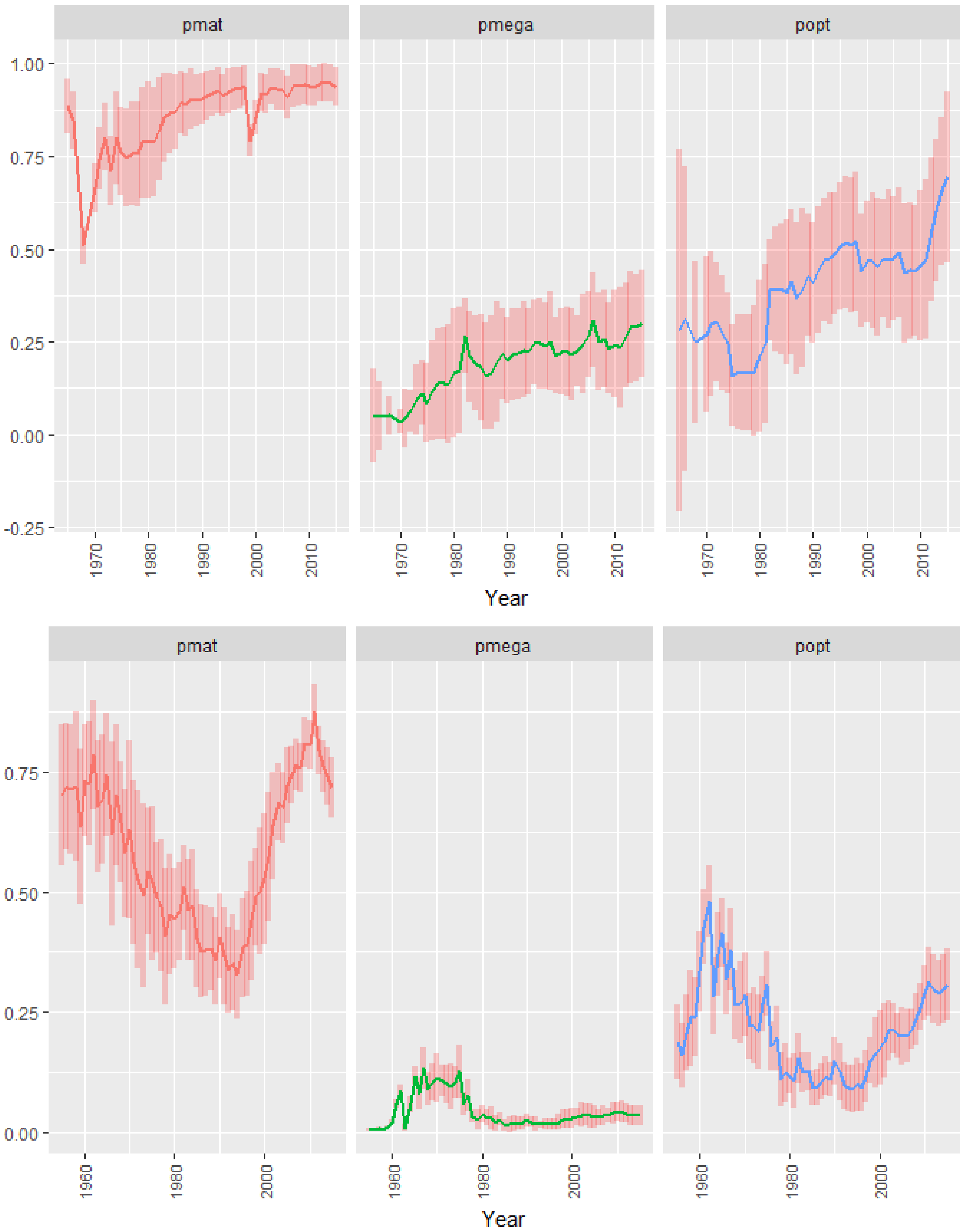

Figure 15. Length based indicators for Bluefin tuna caught within the Western Atlantic (top) and Eastern Atlantic stock areas (bottom). Popt (green), Pmat (red) and Pmega (blue). Task II size revision 4.

R functions for calculating P_{mat}, P_{mega} and P_{opt}.
PL = proportion of catch at length
L_{mat} = length at 50% maturity
L_{max} = the maximum length of the species.
L_{opt} = the length at which maximum yield can be obtained

```
PMAT = function(Lmat,Lmax,length,number=NULL){
 if(is.null(number[1])){number = 1}
 data = data.frame(length=length,number=number)
 data = aggregate(number~length,data,sum)
 data = data[order(data$length),]
 data$cumsum = cumsum(data$number)
 # calculate proportion between Lmat and Lmax
 N = rev(which(data$length<=Lmax))[1]
 N = data$cumsum[N]
 Pmat = rev(which(data$length<Lmat))[1]
 n = data$cumsum[Pmat]
 if(is.na(n)){n=0}  # sometimes all the fish are over Lmat
 Pmat = (N-n)/N
 print(Pmat)
 }

POPT = function(Lopt,length,number=NULL){
 if(is.null(number[1])){number = 1}
 data = data.frame(length=length,number=number)
 data = aggregate(number~length,data,sum)
 data = data[order(data$length),]
 data$cumsum = cumsum(data$number)
 # calculate proportion between .9Lopt and 1.1Lopt
 N = rev(which(data$length<=1.1*Lopt))[1]
 N = data$cumsum[N]
 Popt = rev(which(data$length<.9*Lopt))[1]
 n = data$cumsum[Popt]
 if(is.na(n)){n=0}  # sometimes all the fish are over .9Lopt
 Popt = (N-n)/N
 print(Popt)
 }

PMEGA = function(Lopt,Lmax,length,number=NULL){
 if(is.null(number[1])){number = 1}
 data = data.frame(length=length,number=number)
 data = aggregate(number~length,data,sum)
 data = data[order(data$length),]
 data$cumsum = cumsum(data$number)
 # calculate proportion between Lmat and Lmax
 N = rev(which(data$length<=Lmax))[1]
 N = data$cumsum[N]
 Pmega = rev(which(data$length<1.1*Lopt))[1]
 n = data$cumsum[Pmega]
 if(is.na(n)){n=0}  # sometimes all the fish are over 1.1Lopt
 Pmega = (N-n)/N
 print(Pmega)
 }
```