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WHICH CAME FIRST? THE CHICKEN, THE EGG OR THE TORTILLA

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SUMMARY

In this paper we look for evidence of a stock recruitment relationships for bluefin, yellowfin and albacore tuna. Evidence of the existence of a SRR for any of the stock was weak and the data instead appear to support the argument that recruitment fluctuates around a mean level for a period and then a regime shift occurs. This has obvious important implications for stock assessment and management advice

RÉSUMÉ

Dans le présent document, nous recherchons des éléments de preuve d'une relation stock recrutement pour le thon rouge, l'albacore et le germon. Les preuves de l'existence d'une SRR pour l'un quelconque des stocks étaient faibles et les données semblent plutôt étayer l'hypothèse selon laquelle le recrutement fluctue autour d'un niveau moyen pendant une période de temps, puis un changement de régime survient. Ceci a clairement d'importantes implications pour l'évaluation des stocks et l'avis de gestion.

RESUMEN

En este documento se buscan evidencias de relaciones stock- reclutamiento para el atún rojo, el rabil y el atún blanco. Las evidencias de la existencia de una SRR para estos stocks eran débiles y, en su lugar, los datos parecían apoyar el argumento de que el reclutamiento fluctúa en torno a un nivel medio para un periodo y posteriormente se produce un cambio de régimen. Esto tiene obvias implicaciones para la evaluación de stock y el asesoramiento en materia de ordenación.

KEYWORDS

Fishery statistics, Fishing Effort, Longline fisheries, Time-space distribution

Introduction

Density dependence is required to stabilise population models, since in the absence of density dependence a population will would eventually increase or decrease without bound (May, 1986). The stock recruitment relationship (SRR) is often the only form of density dependence assumed in stock assessment models, despite the fact that it can occur in many biological processes (Lorenzen and Enberg, 2002), mainly because it is difficult to detect in practice (Sinclair *et al*., 2002). Density dependence has important effects on extinction risks (Ginzburg *et al*., 1990) and population growth rates (Hassell, 1975) and hence reference points.

The information in stock assessment data sets is seldom sufficient to derive the relationship between stock and recruitment (Lee *et al*., 2012). It has also been known for nearly a century (Hjort, 1926) that fish stocks can fluctuate extensively over a large range of spatial and temporal scales independent of human exploitation. Gilbert (1997) argued that recruitment may shift between regimes independently of stock biomass and that spawning stock biomass (SSB) is a function of recruitment, i.e. periods of high or low recruitment generate periods of high or low stock biomass respectively as fish mature. Vert-pre *et al*., (2013) posed four hypotheses

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related to recruitment processes i.e. i) that recruitment is a function of population size, ii) that productivity shifts irregularly between regimes that are unrelated to abundance; iii) the mixed hypothesis, where even though production is related to population abundance, there are irregular changes in this relationship; and (iv) the random hypothesis, where production is random from year to year. If irregular changes in productivity are common, this has implications for management targets and limits based on reference points which may need to be adjusted when productivity changes.

Material and methods

Non-parameteric SRRs were fitted to stock and recruit time series obtained from ICCAT stock assessments. Evidence for autocorrelation in recruitment, cross correlations between recruitment and SSB and regime shifts was then examined.

Data

Time series of SSB and recruitment were obtained from the most recent ICCAT stock assessments for North Atlantic albacore, Eastern and Western Altantic bluefin and yellowfin tunas. The albacore assessment was conducted using Multifan-CL while the other stocks were assessed using virtual population analysis (VPA). In all cases there were no constraints on SRR parameters. For Western Altantic bluefin two catch time series were considered, i.e. the reported catches and an inflated catch series which allowed for catch misreporting.

Methods

Stock recruitment relationships

The Beverton and Holt SRR (Beverton and Holt, 1993) is derived from a simple density dependent mortality model where it is assumed that mortality of pre recruits is proportional to their density and the number of recruits increases towards an asymptotic level (R max) as egg production increases. The Ricker SRR assumes that density dependent mortality is proportional to the initial number of eggs or larvae. This may be appropriate when a prey species is temporarily massed in unusual numbers and the number of prey eaten depends on the abundance of predators, but not on the abundance of prey. Hence such situations cannot last long, and the predators cannot make the prey in question their principal yearly food, Ricker (1987). Alternative mechanisms include cannibalism, habitat limitations, and aggregation (Rose *et al*., 2001, Brooks and Powers, 2007, Powers, 2004).

The majority of fisheries stock assessment modelling is parametric. However when modelling the relationship between stock and recruitment models may not adequately explain the data or the data may not informative enough to estimate the parameters Hillary *et al*. (2012). Therefore we fitted a LOESS smoother (Cleveland *et al*., 1992) to allow the relationship between stock and recruitment to be explored without specifying in advance the assumed process (i.e. compensation, over compensation or depensation) as required when fitting one of the standard functional forms. We then look for patterns in the residuals that may indicate that other processes influence recruitment.

Cross correlations

In order to evaluate whether there is a monotonic relationship between recruitment and SRP (see Szuwalski et al, submitted) cross correlations were calculated based on Spearman's correlation (Spearman, 1904). If there is compensation (for example recruitment follows a Beverton and Holt stock recruitment relationship) then there will be a significant correlation equal to the age at recruitment. (The significance levels in the plots are probably wrong due to auto-correlation in the time series. 2 options either to i) remove the CI or ii) calculate new corrected ones based on Pyper and Peterman (1998))

However if stock biomass is driven by recruitment as a result of fluctuations in the environment (?) then there will be negative lags at corresponding to the mature ages. Only if SSB has a larger and significant influence on recruitment than recruitment does on SSB then is the existence of a S-R is supported (Szuwalski *et al.*, submitted).

Regime shifts

Evidence for regime shifts are explored using a a sequential t-test algorithm (STARS; Rodionov (2004)) as modified by Szuwalski *et al.* (submitted).

Results

Time series of recruitment and SSB are shown in **Figures 1 and 2**. Recruitment is then plotted against SSB along with a non-parameteric LOESS fit in **Figure 3**. The residuals to the fits are shown in **Figure 4**. Results from the Eastern Atlantic bluefin inflated catch time series are in red. Autocorrelation in the recruitment time series are evaluated by plotting correlogrammes in **Figure 5** for recruitment and for recruitment residuals from the non-parameteric fits in **Figure 6**. To check the assumption that there is monotonic relationships between recruitment and SSB (e.g. a Beverton and Holt stock recruitment relationship without over compensation) the cross Spearman correlations are plotted in **Figure 7**. For yellowfin points on the right-hand limb of the Ricker curve were from early in the time series, these were removed prior to calculating cross correlations. Sequential t tests for regime shifts (Rodionov, 2004) in recruitment are shown in **Figure 8**, for residuals from the non-parameteric fits in **Figure 9** and for SSB in **Figure 10**.

The SRR is explored in **Figure 3**; a Ricker SRR is suggested for yellowfin, however the points on the right-hand limb of the Ricker curve all come from the early period of the time series and could also be explained by a regime shift. For albacore a Beverton and Holt or Ricker for albacore could be fitted to the data.

For the bluefin time series the picture is less clear. For the eastern stock low recruitments are seen with higher levels of SSB, which could be consistent with over compensation. For the western stock, recruitment declined year-on-year from the start of the time series until stabilising in recent years to a low level about which recruitment has fluctuated.

Residual patterns in **Figure 4** shows a systematic pattern, i.e. recruitment in the early years was lower than predicted. There is no systematic pattern in the albacore residuals. For Eastern bluefin recent recruitment is lower than the predicted values, although values from VPA are less reliable in the most recent years. For Western bluefin in the mid period, when recruitment was declining year-on-year the residuals are all positive. **Figures 3 and 4** indicate problems with all the fits apart from albacore.

Autocorrelation plots in **Figure 5** show significance autocorrelation for all-time series other than albacore. In the albacore assessment recruitment deviates were estimated as a random walk and so autocorrelation was removed from the residuals. The residuals from the non-parameteric fits show less autocorrelation (**Figure 6**) since the smoother has removed some of the trends since recruitment and SSB are correlated as seen by the cross correlations.

Cross correlation plots (**Figure 7**) do not support recruitment being driven by SSB, since there a lag of 1 for recruitment (i.e. at age 1) with SSB is no more important than other lags. For Eastern Atlantic bluefin the cross correlations are negative with lags less than 1 being the most significant.

If there was overcompensation then there should be a significant negative correlation with a lag of 1. The cross correlations therefore do not support the existence of a stock-recruitment relationship. Teleosts generally produce a large number of eggs with only a small number survive to recruitment. This has nothing to do with fishing since the stock recruitment relationship only considers the pre-exploitation stage and fishing reduces the spawning stock not recruitment. Therefore positive lags are not affected by fishing. However, negative lags are as the numbers surviving to maturity are determined by mortality levels. Regime shifts are explored in **Figures 8** and 9 overlay the regime shifts on the recruitment and recruit residual time series. If it is believed that there is no stock recruitment relationship then in all stocks there are regime shifts (i.e. in both the mean and variance) in recruitment about every 10 years. The regime shifts in SSB for Western Atlantic bluefin and yellowfin coincide with those in recruitment. However, the regime shifts in Eastern bluefin and albacore show large variations which do not obviously coincide with those in recruitment.

Discussion and conclusions

For Eastern Atlantic bluefin three recruitment scenarios were considered in the projections corresponding to hypothesis that productivity has shifted between regimes that are unrelated to abundance. If regime shift hypotheses was thought to be more probable then more weight could be given to recent recruitments.

For Western Atlantic Bluefin two recruitment scenarios were considered, i.e. Beverton and Holt and segmented regression stock recruitment relationships. Both scenarios were judged to be equally likely with an explicit assumption that more information would identify the correct relationship. Fromentin *et al*. (2013) identified a possible explanation for a regime shift and Simon *et al.* (2012).

In the case of North Atlantic albacore a Beverton and Holt stock recruitment relationship was fitted as part of the assessment model. However, there was no information to estimate steepness in the data and this parameter hit the upper bound of 0.9, i.e. that recruitment is consistent with yellowfin (iv) the random hypothesis was assumed The results show that evidence supporting the existence of a SRR for any of the stock is weak.

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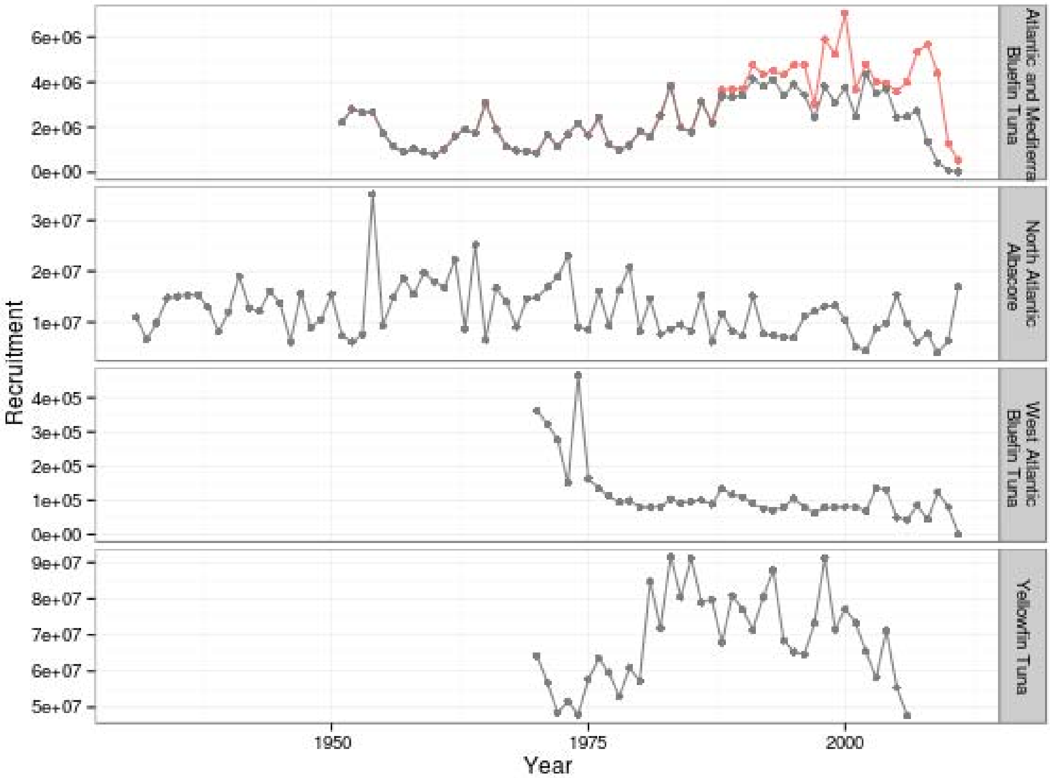

Figure 1. Time series of recruitment; the red lines represent the eastern Atlantic bluefin series based on the inflated catch.

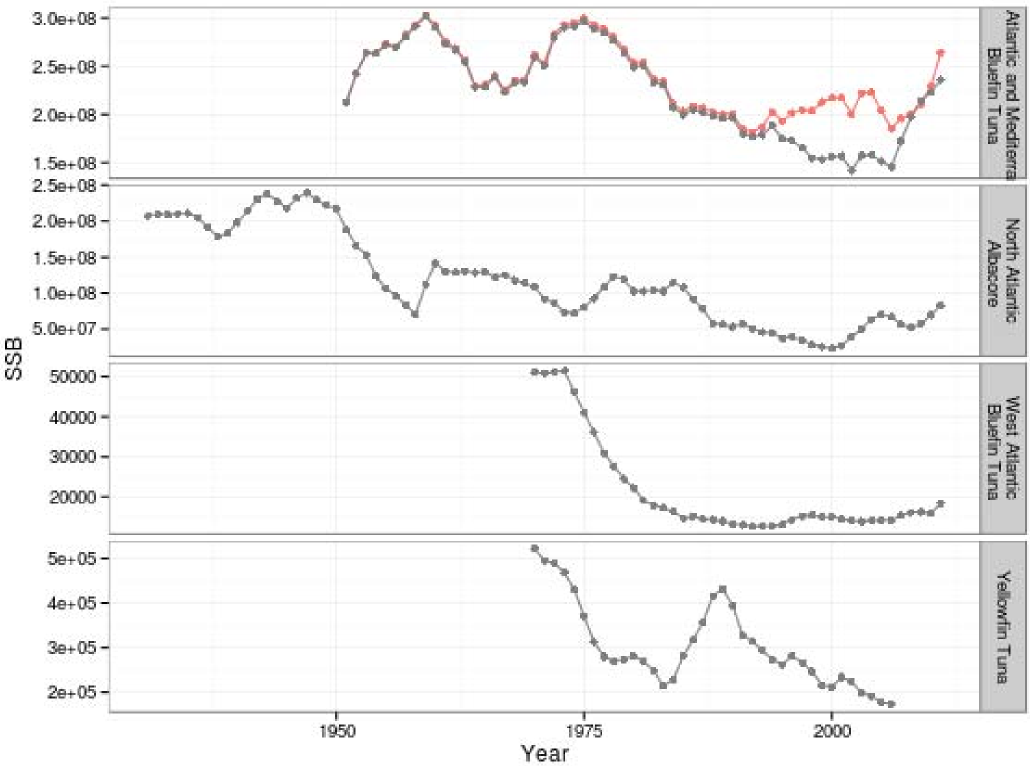

Figure 2. Time series of Spawning Stock Biomass.

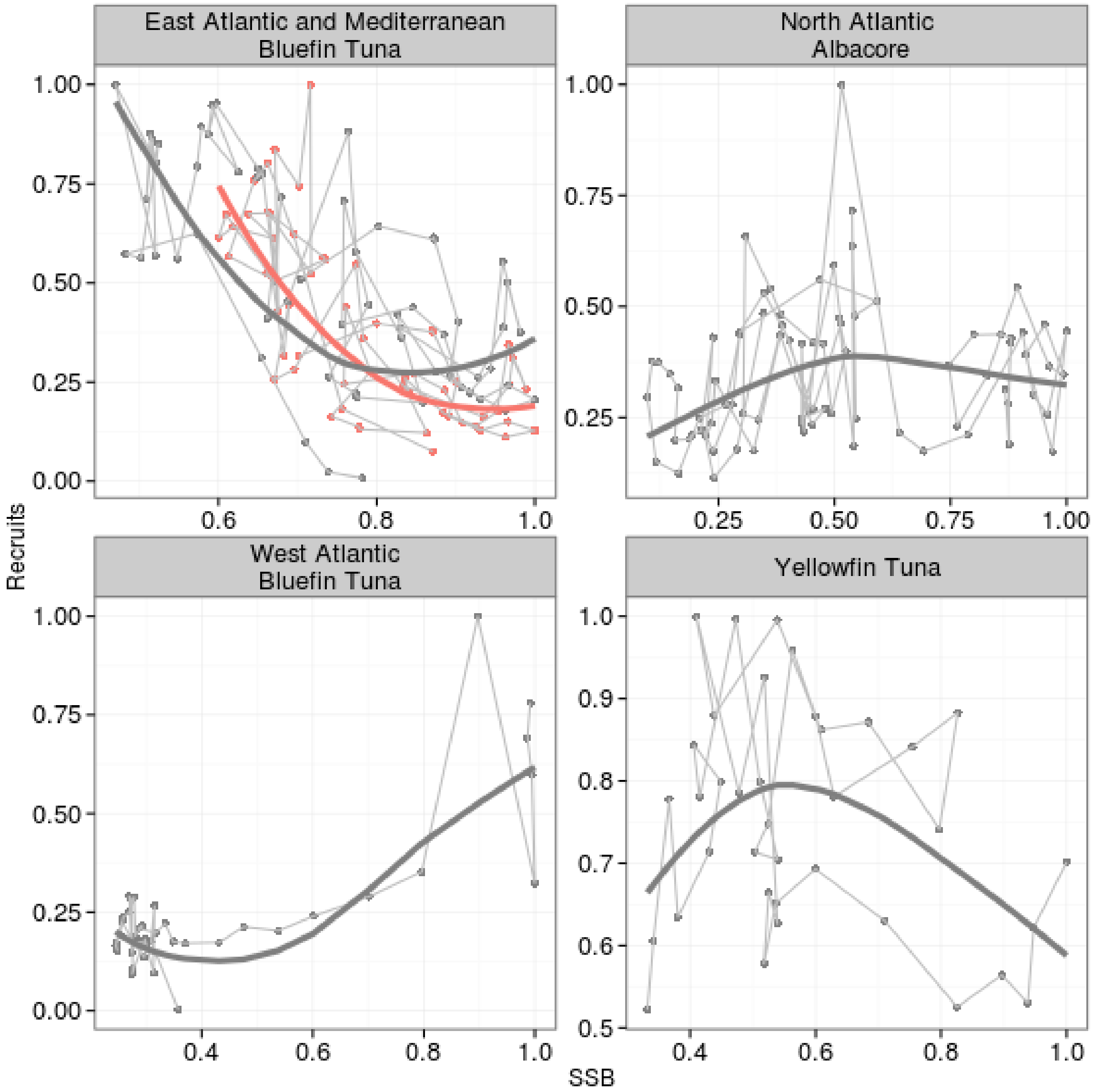

Figure 3. Plots of Recruitment against Spawning Stock Biomass, with non-parameteric fits using a LOWESS smoother.

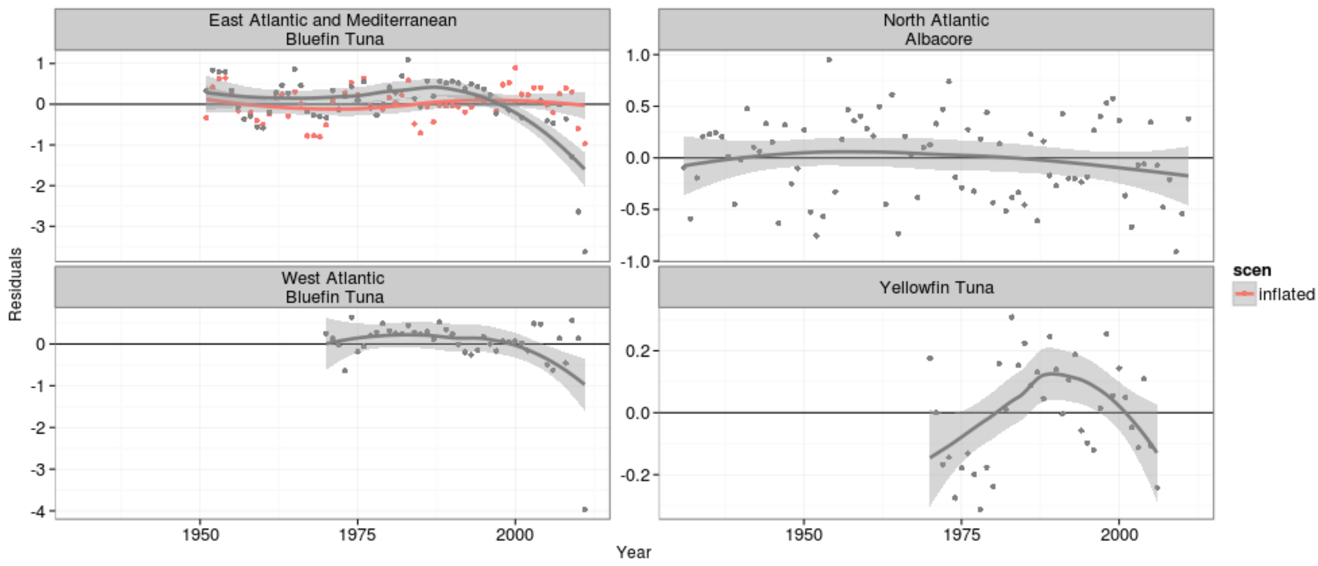

Figure 4. Plots of residuals from non-parameteric fits to Recruitment as a function of Spawning Stock Biomass.

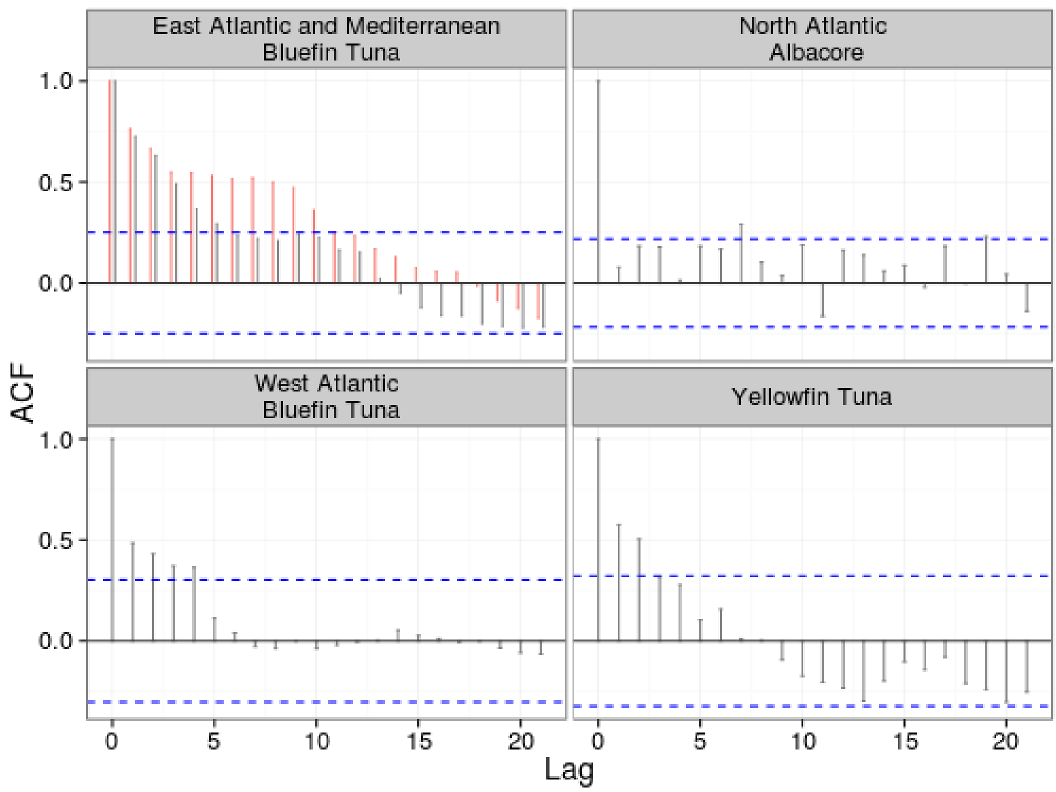

Figure 5. Plots of recruitment auto correlation, horizontal lines are the 5\% Cis.

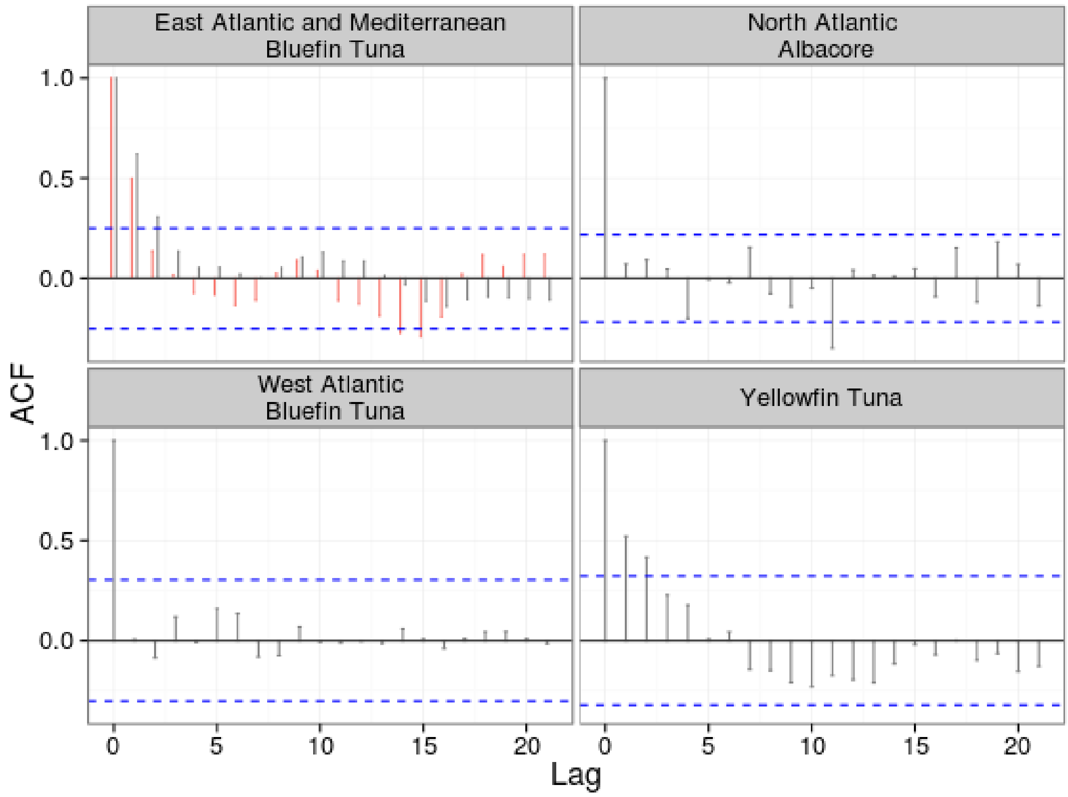

Figure 6. Plots of recruitment residuals auto correlation, horizontal lines are the 5\% Cis.

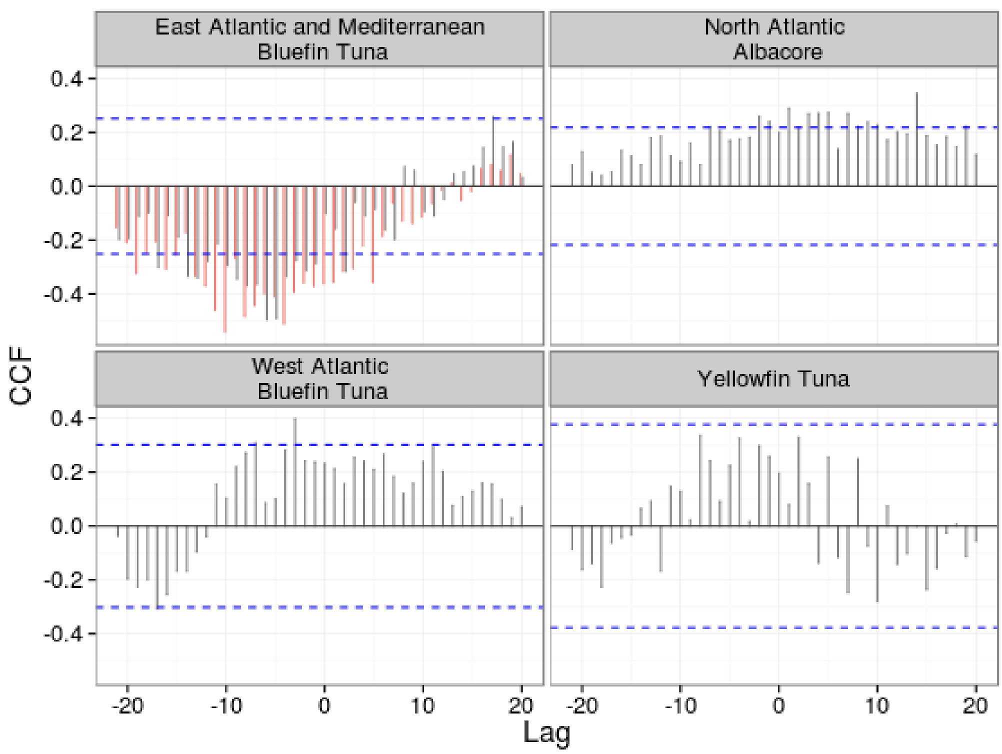

Figure 7. Plots of cross correlation between recruitment and SRP, horizontal lines are the 5\% Cis.

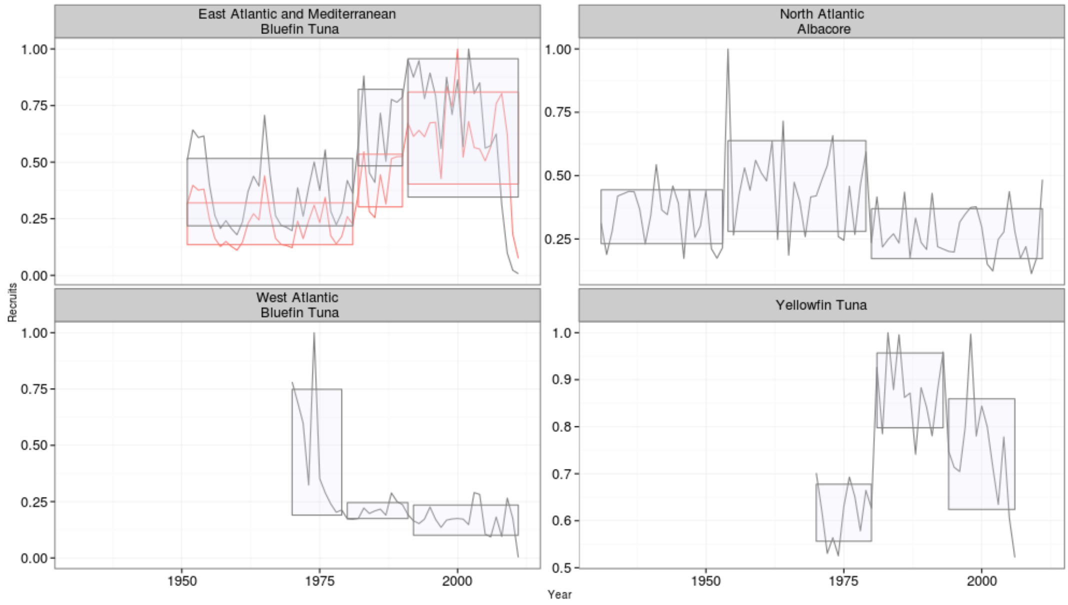

Figure 8. Recruitment by year Sequential t test for regime shifts (Rodionov, 2004) in recruitment.

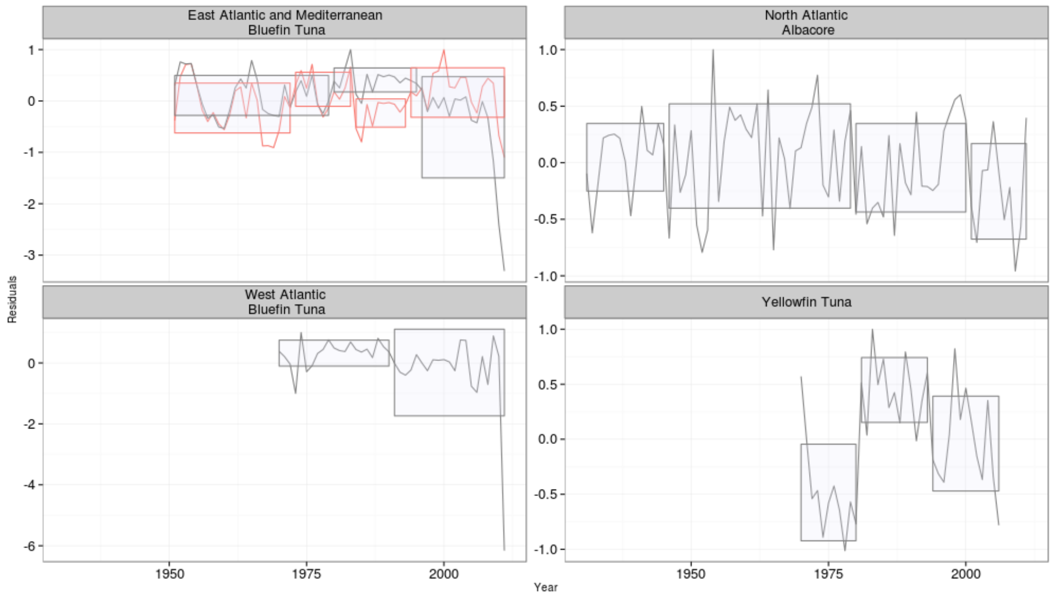

Figure 9. Recruitment by year Sequential t test for regime shifts (Rodionov, 2004) in recruitment residuals.

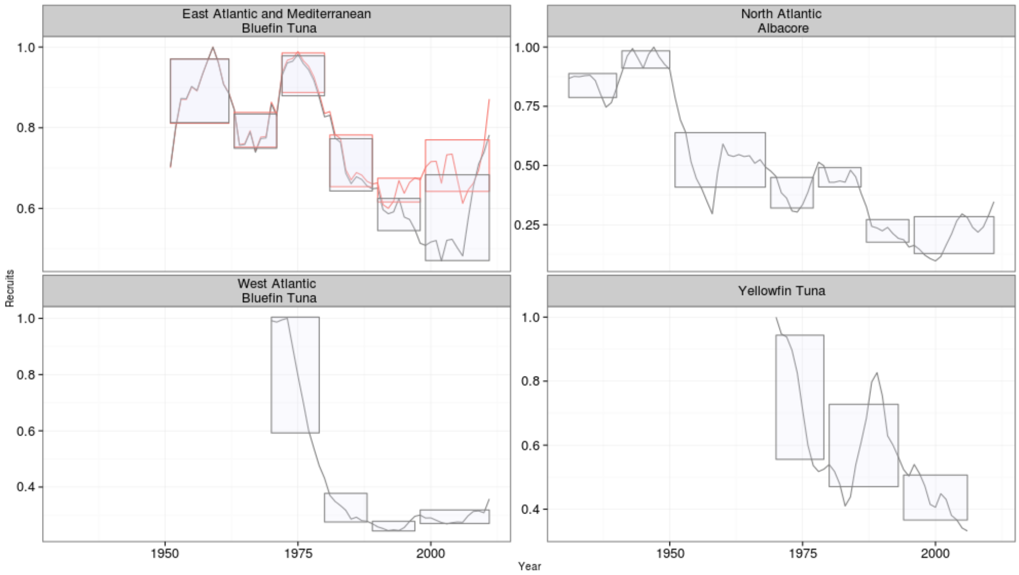

Figure 10. Recruitment by year Sequential t test for regime shifts (Rodionov, 2004) in SSB.