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UPDATED CATCH-AT-AGE ANALYSES OF WEST ATLANTIC BLUEFIN TUNA 1960-1997

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SUMMARY

*The age-structured model CATCHEM (Porch and Turner, 1997) is applied to catch and index data for west Atlantic bluefin tuna (*Thunnus thynnus*) from 1960 to 1997. The predictions for recent years are similar in trend to those from the base case assessment of the 1998 SCRS. However, both spawning stock biomass and recruitment were estimated to have been higher during the 1960's than for any subsequent period. Recruitment was more highly correlated with spawning stock biomass than with the NAO index. Although the winter NAO can explain about 25% of the variability in recruitment estimates for the time series examined when used alone, SSB alone can explain about 65% of the variability in year class strength estimates (model 2 in Table 2). When considered jointly, the winter NAO provides no significant additional predictive power relative to SSB (model 3, Table 2).*

RÉSUMÉ

Le modèle structuré par âge CATCHEM (Porch & Turner, 1997) est appliqué ici aux données sur la capture et l'indice du thon rouge (Thunnus thynnus) *de l'Atlantique pour les années 1960 à 1997. Les prédiction des années récentes sont semblables à la tendance de celles de l'évaluation du cas de base effectuée en 1998 par le SCRS. Toutefois, on a estimé que la biomasse du stock reproducteur comme le recrutement ont été plus importants pendant les années 1960 que durant toute période ultérieure. Le recrutement montrait une plus forte corrélation avec la biomasse du stock reproducteur qu'avec l'indice NAO. Bien que le NAO d'hiver puisse justifier environ 25% de la variabilité des estimations du recrutement pour la série temporelle examinée lorsqu'elle est utilisée seule, la seule SSB peut justifier à peu près 65% de la variabilité des estimations de l'importance de la classe annuelle (modèle 2 du Tableau 2). Lorsqu'on les observe ensemble, le NAO d'hiver ne montre pas une puissance de prédiction sensiblement plus importante que la SSB (modèle 3, Tableau 2).*

RESUMEN

Se aplica el modelo estructurado por edad CATCHEM (Porch y Turner, 1997) a los datos de captura e índice del atún rojo del Atlántico oeste (Thunnus thynnus) *de 1960 a 1997. Las predicciones para los últimos años son similares en tendencia a las de la evaluación del caso base hecha en 1998 por el SCRS. Sin embargo, se estimó que tanto la biomasa del stock reproductor como el reclutamiento habían sido más altos en los años 60 que en cualquier otro período posterior. El reclutamiento presentaba una correlación más alta con la biomasa del stock reproductor que con el índice NAO. Si bien el índice NAO invernal puede explicar un 25% de la variabilidad en las estimaciones del reclutamiento para la serie temporal examinada cuando se aplica solo, la SSB por sí mima puede explicar alrededor de un 65% de la variabilidad en las estimaciones de la fuerza de la clase anual (modelo 2 en la Tabla 2). Si se consideran en conjunto, el índice NAO invernal no tiene mucho más poder de predicción en relación con la SSB (modelo 3, Tabla 2).*

KEYWORDS

Stock assessment, environmental effects, recruitment, long-term changes

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1. INTRODUCTION

This article presents updated analyses of the catch and abundance index data for West Atlantic bluefin tuna from 1960 to 1997 by use of the catch-at-age model CATCHEM (Porch and Turner, 1997), which is essentially an extension of ADAPT that allows for errors and missing data in the catch at age matrix. The results are compared to corresponding VPA-based ADAPT assessments conducted by the 1998 SCRS.

2. METHODS

2.1 CATCHEM: Model structure

CATCHEM is an age-structured maximum likelihood model that estimates a variety of parameters from fleet-specific data on the total catch, age-composition of the catch, catch per unit effort, and survey indices of abundance. As mentioned earlier, an advantage of this sort of approach over VPA (and the impetus behind the development of this model) is the ability to accommodate gaps in the historical record. The primary disadvantage is that the fishing mortality rates are not uniquely determined by the recursions as in VPA, but must be estimated as parameters. In practice, the number of data points available is insufficient to justify attempting to estimate the fishing mortality rates for every fleet, age and year so that some simplifying assumptions must be made. CATCHEM assumes that the selectivity pattern of each fishing fleet is constant during specific eras (but may vary among eras). The mathematical details, including the population dynamics equations, error models and parameter estimation are presented in the appendix.

2.2 Fleet definitions and assessment data

As far as was possible, the data were treated in a manner consistent with the protocols used by the 1998 SCRS (ICCAT, 1999). Fish older than nine years were lumped together in a plus group. The definition of the West Atlantic stock was the same. The catch at age data were divided into categories corresponding to fisheries with similar age composition and geographic and temporal distributions with particular emphasis on fisheries from which the SCRS had indices of abundance. Those fisheries were: (1) the Canadian fishery combined all tended line and rod and reel catches and this catch at age was used with the Canadian southwest Nova Scotia (SWNS) index from the SCRS; (2) the Japanese longline fishery from 1960-1970 was used with an index from the Florida-Brazil fishery (NMFS 1984; because of the time range no index for this fishery was used by the 1998 SCRS); (3) the Japanese longline fishery in the Northwest Atlantic was defined as occurring since the early 1970's and consisting of ages 1-9and was used with associated index from the SCRS; (4) the US longline fishery consisted of ages 8-10+ and was used with the U.S. longline index from the Gulf of Mexico which covered 1987-1998; the US rod and reel fishery for small fish was divided into two eras: (5) the early period through 1992 was associated with the index for ages 1-5 in 1980-1992; after 1993 the small fish fishery was divided into two components with one index for each: (6) the US rod and reel fishery for ages 1-3 from 1993-1997 and (7) the US rod and reel fishery for ages 4-5 from 1993-1997; (8) the US rod and reel fishery age 6 was associated with the index for that age from 1993-1997; (9) the nearshore mixed-gear fishery for large fish [ages 8+] which was associated with the U.S. large fish rod and reel index. In addition, separate categories were used to represent US purse-seine catches of (10) small fish [ages 1-5] and (11) large fish [ages 6+]; there were no indices for those fisheries. A twelfth category was added to accommodate the catches of other minor fisheries. The larval survey, Canadian tended line, Japanese Gulf of Mexico longline and tagging indices used in the 1998 SCRS assessment were also included, but were treated essentially as fishery independent indices of abundance with known selectivities (as done by the SCRS). No CPUE indices were included for the US purse-seine and 'other' fisheries.

The catchability and selectivity-at-age parameters for some of the fisheries were allowed to vary among several blocks of years (eras) corresponding to time periods with potentially significant changes in the fishing. methods or fishing grounds. These are summarized in Table 1. The remaining estimated parameters include the annual recruitments, initial age structure of the population in 1960, apical fishing mortality rates for each year of each fishery, and four catchability coefficients (for the four surveys) .

3. RESULTS AND DISCUSSION

The CATCHEM assessment presented here should be regarded as an example only. It is meant to illustrate the potential of the methodology rather than to make a definitive statement on the status of the western Atlantic bluefin resource. We recognize that the fishery definitions and CPUE indices used in this example may not be the most appropriate. Refinements in the input specifications for the model may be made through discussion and analysis at the 2000 ICCAT SCRS bluefin assessment.

The estimates of abundance from CATCHEM are compared with the ADAPT VPA results reported by the 1998 SCRS in Figure 1. The two sets of estimates were generally quite similar over the years they had in common, particularly in regards to the relative trends. Both indicate that the abundance of age 1, 2-5, and 8+ fish has declined substantially since the 1970's. The CATCHEM model predicted much lower abundances for young fish in the most recent years, however these values are poorly estimated in both models (the 1999 SCRS report does not show the VPA estimates for young fish after 1994, but replaces them based on the recruitment expected from a spawner-recruit curve). The abundance of the older age groups is estimated to be slightly lower with CATCHEM than by the SCRS VPA, which may be a consequence of the way the selectivities are fixed in the VPA, but the relative trends are nearly identical.

The estimates of recruitment from the 1960's suggest that the high levels observed during the early 1970's were not anomalous, but typical of the era from 1960-1975 when the spawning stock biomass was also much higher (Figure 2). A Beverton Holt stock recruitment model fit to these stock and recruitment estimates under the constraint that maximum recruitment could not exceed the average of the 3 highest estimated values, yields a predicted equilibrium recruitment level at SSB_{MSY} of about 290,000 fish, a level considerably higher than the estimated average since 1976.

It has been suggested that environmental conditions, such as indexed by the winter North Atlantic Oscillation (NAO, see Hurrell, 1995, Figure 3), are correlated with recruitment of north Atlantic bluefin in the eastern Atlantic and Mediterranean (Santiago 1998, Santiago 1999). Santiago hypothesized that situations of intensified atmospheric circulation in the north Atlantic as indexed by high positive values of the NAO, indirectly favored the level of recruitment of eastern Atlantic and Mediterranean northern bluefin tuna, but had the reverse effect on northern Atlantic albacore recruitment. For western Atlantic bluefin recruitment, Santiago (1998) found no significant indication of correlation between the NAO and year-class strength estimates for western Atlantic northern bluefin, but found correlations between the NAO and eastern bluefin (and northern albacore) year-class strength estimates. The degree to which the correlations would persists under different hypotheses related to change in the rate of accounting for small fish catches over time for eastern bluefin, was not evaluated. Also, Mejuto (1999, 2000) found correlation between swordfish young of the year index values from the Spanish fleet and the NAO for a time-series of 1983-1998. These correlations, however, were found to vary with the index of small fish abundance considered as well as with the specific form of the NAO used for evaluation (see SCRS 1999 Swordfish Detailed Report Det/99/SWO). The SWO working group found that although correlated, there is considerable deviation between the annual values from the winter NAO index (used in Mejuto 1999, 2000) and the annual values calculated from the SPL differences between Ponta Delgada and Reyjavik (see Figure 3). Correlation between these two series and the standardized catch rates of age 0 swordfish from the US fishery (Ortiz, *et.al.* 2000), could be positively, negatively, or largely uncorrelated with either of the two NAO series used in correlation analysis. The highest correlations in the USA time series (which were shorter than the Spanish index) were positive, unlike the Spanish age 1 index information, which were negative. Mejuto (1999, 2000) used standardized CPUE age 1 catch rates because age zero catches are generally very low in the Spanish catches and only a very small proportion of age 0 fish appears recruited to Spanish longline gear. He applied the winter NAO because it was thought to be a closer representation of the seasonal peak in swordfish spawning. It was noted, however (1999 SWO Detailed Report) that in order to attempt correlative analyses between environment factors and data from fisheries (such as estimated recruitment levels from CPUEs) appropiate indicators must be defined for each fishery. Additionally, the level of correlation is largely affected by the quality (confidence) of the data available for each fishery. In any case, the time series considered for swordfish are short with respect to the generation time for swordfish considering the apparent 20 year cycle in the average NAO index. Given this fact, the SWO group indicated that the possibility of spurious correlations has to be considered during correlative evaluations of environmental and fishery time-series.

The correlation with the winter NAO (following Santiago and Mejuto, as described above) with the estimated recruitment values from the present study over the 1960-1995 period (as in the most recent west Atlantic bluefin VPA, year class strength estimates since 1995 were discounted) (see Figure 4), shows a tendency in the paired observations for higher estimates of recruitment with lower NAO values, although with considerable scatter. At the same time, there is also a positive correlation between recruitment and spawning stock size (Figure 2). A simple linear model applying the winter NAO values and the spawning stock biomass estimates from the present study to predict 1 year lagged recruitment estimates, shows a much stronger predictive relationship between SSB and recruits than between NAO and year class strength (Table 2). Although the winter NAO can explain about 25% of the variability in recruitment estimates for the time series examined when used alone, SSB alone can explain about 65% of the variability in year class strength estimates (model 2 in Table 2). When considered jointly, the winter NAO provides no significant additional predictive power relative to SSB (model 3, Table 2).

Under an hypothesis that environmental variability as measured through the winter NAO affects survivorship of young of the year, one would expect to observe tendency in survival ratios (R/SSB) with the winter NAO. For the estimates available from the present study, R/SSB estimates are uncorrelated with NAO (see Figure 5). The pattern in estimated R/SSB from the present study appears to show a negative correlation with the pattern in normalized catches of age 10 and older westernAtlantic northern bluefin (Figure 6).

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APENDIX: MODEL DESCRIPTION

Calculation of population statistics

The CATCHEM algorithm essentially consists of an age-structured simulation model set within the statistical estimation framework developed by Fournier and Archibald (1982). Like many other modern assessment tools, CATCHEM allows considerable flexibility with respect to how a problem may be approached. This requires the investigator to think carefully about the assumptions he or she is willing to make. The equations used to model the underlying population dynamics, however, are the standard forms familiar to any student of fisheries science:

$$N_{a,y} = \begin{cases} N_{\alpha,y} & (a = \alpha) \\ N_{a,\psi} & (y = \psi,\ a > \alpha) \\ N_{a-1,y-1} e^{-Z_{a-1,y-1}} & (y > \psi,\ \alpha < a < A) \\ N_{A,y-1} e^{-Z_{A,y-1}} + N_{A-1,y-1} e^{-Z_{A-1,y-1}} & (a = A) \end{cases}$$

$$c_{f,a,y} = F_{f,a,y}\left(1 - e^{-Z_{a,y}}\right) N_{a,y} / Z_{a,y}$$

$$C_{f,y} = \sum_{a=\alpha}^{A} c_{f,a,y} \text{ or , in terms of weight, } \sum_{a=\alpha}^{A} c_{f,a,y}\ w_{i,a,y}$$

$$U_{f,y} = q_{f,y} \sum_{a=\alpha}^{A} s_{f,a,y}\ w_{f,a,y}\, N_{a,y}\left(1 - e^{-Z_{a,y}}\right) / Z_{a,y}$$

$$x_{i,a,y} = q_{i,y} s_{i,a,y} N_{a,y}\left(1 - e^{-Z_{a,y}}\right) / Z_{a,y}$$

$$X_{i,y} = \sum_{a=\alpha}^{A} x_{i,a,y}\ w_{i,a,y}$$

$$Z_{a,y} = \sum_{f} F_{f,a,y} + M_{a,y}$$

$$F_{f,a,y} = \phi_{f,y} s_{f,a,y}$$

(A1)

where a = youngest age class
- A = oldest age class
- y = first year (or season)
- Y = last year (or season)
- $N_{a,y}$ = initial abundance of age class *a* in year/season *y*
- $c_{f,a,y}$ = catch in numbers of age class *a* in year/season *y* by fishery *f*
- $C_{f,y}$ = total catch in numbers of all ages in year/season *y* by fishery *f*
- $U_{f,y}$ = catch per unit effort index of abundance for year/season *y* from fishery *f*
- $x_{i,a,y}$ = catch in numbers of age class *a* in year/season *y* by survey *i*
- $X_{i,y}$ = total catch (index of abundance) for year/season *y* by survey *i*
- $Z_{a,y}$ = instantaneous total mortality rate for age class *a* in year *y*.
- $F_{f,a,y}$ = instantaneous fishing mortality rate exerted on age class *a* in year *y* by fishery *f*
- $s_{k,a,y}$ = relative selectivity on age a in year y for a given fishery (*k=f*) or survey (*k=i*).
- $f_{f,y}$ = instantaneous fishing mortality rate on the most heavily exploited age class
- $M_{a,y}$ = instantaneous natural mortality rate exerted on age class *a* in year y
- $w_{k,,a,y}$ = average weight at age for a given fishery (*k=f*) or survey (*k=i*).

The parameters that may be estimated are the recruitments ($N_{a,y}$); initial population age structure ($N_{a,y}$); natural mortality rates ($M_{a,y}$); fishery-specific fishing mortality rates ($F_{f,a,y}$), selectivities ($s_{f,a,y}$), catchabilities ($q_{f,y}$) and growth parameters ($v_{f,a}$, $k_{1,f}$, $t_{1,f}$, $k_{2,f}$, $t_{2,f}$); and survey-specific selectivities ($s_{i,a,y}$), catchabilities ($q_{i,y}$) and growth parameters ($v_{i,a}$, $k_{1,i}$, $t_{1,i}$, $k_{2,i}$, $t_{2,i}$). In most applications there are not enough data to estimate all these parameters effectively and it is necessary to make some simplifying assumptions. Program CATCHEM has many options in this regard, ranging from fixing some parameters at preconceived values to adopting a random walk time series structure (Gudmundsson, 1994; Ianelli and Fournier, 1998).

In the present analysis the following assumptions were made to reduce the number of parameters that must be estimated:
(1) the age dependent effects on fishing mortality (the selectivities) are essentially constant within each fishery during the eras indicated in Table 1;
(2) likewise, the efficiency (q) of the cpue and survey indices of abundance varies insignificantly from one year to the next within eras;
(3) the natural mortality rate is known (0.14) and varies little from one year to the next;

Statistical model and parameter estimation

The parameters to be estimated include the 4 survey catchabilities, maximum fishing mortality rates (by fishery and year), selectivities (by fishery,age, and era), population age structure in the first year, and the annual recruitments. The challenge is to find the estimates that provide the closest agreement between the data and the equivalent model predictions. CATCHEM does this using standard maximum likelihood (or maximum posterior) techniques. The comparison between the data and model predictions is quantified in terms of an overall objective function that is comprised of the sum of the log-likelihood expressions specific to each type of data. In the present application there are four basic types of data-- total catch, catch age composition, CPUE, and survey indices of abundance. Assuming total catch is approximately normal-distributed, the appropriate log-likelihood formula for each fishery is

$$^{C}L_f = \sum_y -0.5\left(\frac{C_{f,y} - \hat{C}_{f,y}}{\sigma_{c,f,y}}\right)^2 - \log_e\left[\sigma_{c,f,y}\right]$$

where $C_{f,y}$ is the observed total catch, $\hat{C}_{f,y}$ is the corresponding model prediction, and $s_{c,f,y}$ is the standard error of $C_{f,y}$. The same formula is applied whether total catch is recorded in terms of numbers or weight.

Data describing the age and length composition of a sample ought to be multinomially distributed provided measurement error is low. In that case, the appropriate log-likelihood functions for theage composition of the catch are

$$^{ca}L_f = \sum_y {}^{ca}n_{f,y} \sum_a r_{f,y,a} \log_e\left[\hat{r}_{f,y,a}\right]$$

where r is the observed proportion of the catch sample in each age class a , $\hat{r}$ is the corresponding model prediction, and n denotes the number of fish in the samples.

Finally, the CPUE and survey indices of abundance are assumed to be lognormally distributed as is done in most stock assessments. The resulting log-likelihood formulae are

$$^{U}L_f = \sum_y -0.5\left(\frac{\log_e\left[U_{f,y} / \hat{U}_{f,y}\right]}{\sigma_{U,f,y}}\right)^2 - \log_e\left[\sigma_{U,f,y}\right]$$

$$^{X}L_i = \sum_y -0.5\left(\frac{\log_e\left[X_{i,y} / \hat{X}_{i,y}\right]}{\sigma_{X,i,y}}\right)^2 - \log_e\left[\sigma_{X,i,y}\right]$$

where s is the standard error of the observations on a logarithmic scale, which may be computed from the sample coefficients of variation (cv) as the square root of $\log_e[cv^2+1]$.

The final objective function is comprised of the individual components above summed over all fisheries and indices of abundance–

$$\sum_f \{{}^{C}L_f + {}^{ca}L_f + {}^{U}L_f\} + \sum_i \{{}^{X}L_i\} \quad . \qquad \text{(A4)}$$

The parameters $\boldsymbol{\Theta}$ that maximize equation (A4) were found using the Nelder-Mead simplex algorithm AMOEBA (Press et al., 1994) with multiple 'restarts' to avoid being fooled by local minima in the solution surface.

Table 1. Eras with constant selectivity patterns and constant catchabilities for each of the 12 fisheries.

Fishery	Eras	Comments
1) Canada SWNS	1960-1987	only ages 9 and 10+ caught
	1988-1997	ages 5 and older caught
2) Japanese LL Fla.-Brazil	1960-1970	ages 4 to 10+ , fishery essentially ends after 1970
3) Japanese LL NW Atl	1971-1988	deep freezers introduced to Japanese fleet
	1989-1997	Japan ceases fishing in Exclusive Economic Zone
4) US LL	1963 -1993	ages 8 to 10+, primarily Gulf of Mexico since the mid 1980's, fishery severely curtailed after 1993
5) US RR (age 1-5)	1960-1992	
6) US RR (age 1-3)	1993-1997	
7) US RR (age 4-5)	1993-1997	
8) US RR (age 6)	1993-1997	
9) US LG mixed gear	1960-1997	ages 8 to 10+
10) Purse seine (small)	1960-1984	targets ages 1 to 5, fishery essentially ends after 1984
11) Purse seine (large)	1960-1997	targets ages 6 to 10
12) Other	1960-1997	ages 2 to 10, various minor fisheries combined

Table 2. Analysis of variance for linear models examining the relative capacity for predicting CATCHEM estimated recruitment (lagged 1 year) using the winter NAO index (WNAO) and Spawning Stock Biomass (SSB) estimates from the present study.

Model 1 Recruits = WinterNAO + error

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.696215E11	1.696215E11	12.44	0.0012
Error	34	4.636219E11	13635938946		
Corrected Total	35	6.332435E11			

Root MSE	116773		
Dependent Mean	154336	Adj R-Sq	0.2463

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	165305	19709	8.39	<.0001
WNAO	1	-29250	8293.42	-3.53	0.0012

Model 2: Recruits = SSB + error

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	4.095908E11	4.095908E11	62.27	<.0001
Error	34	2.236527E11	6578020425		
Corrected Total	35	6.332435E11			

Root MSE	81105		
Dependent Mean	154336	Adj R-Sq	0.6364
Coeff Var	52.55098		

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-29845	26973	-1.11	0.2763
SSB	1	0.00857	0.00109	7.89	<.0001

Model 3: Recruits=Winter NAO + SSB + error

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	4.111917E11	2.055958E11	30.55	<.0001
Error	33	2.220518E11	6728841727		
Corrected Total	35	6.332435E11			

Root MSE	82030		
Dependent Mean	154336	Adj R-Sq	0.6281

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-20037	33890	-0.59	0.5584
WNAO	1	-3529.77869	7236.57661	-0.49	0.6289
SSB	1	0.00817	0.00136	5.99	<.0001

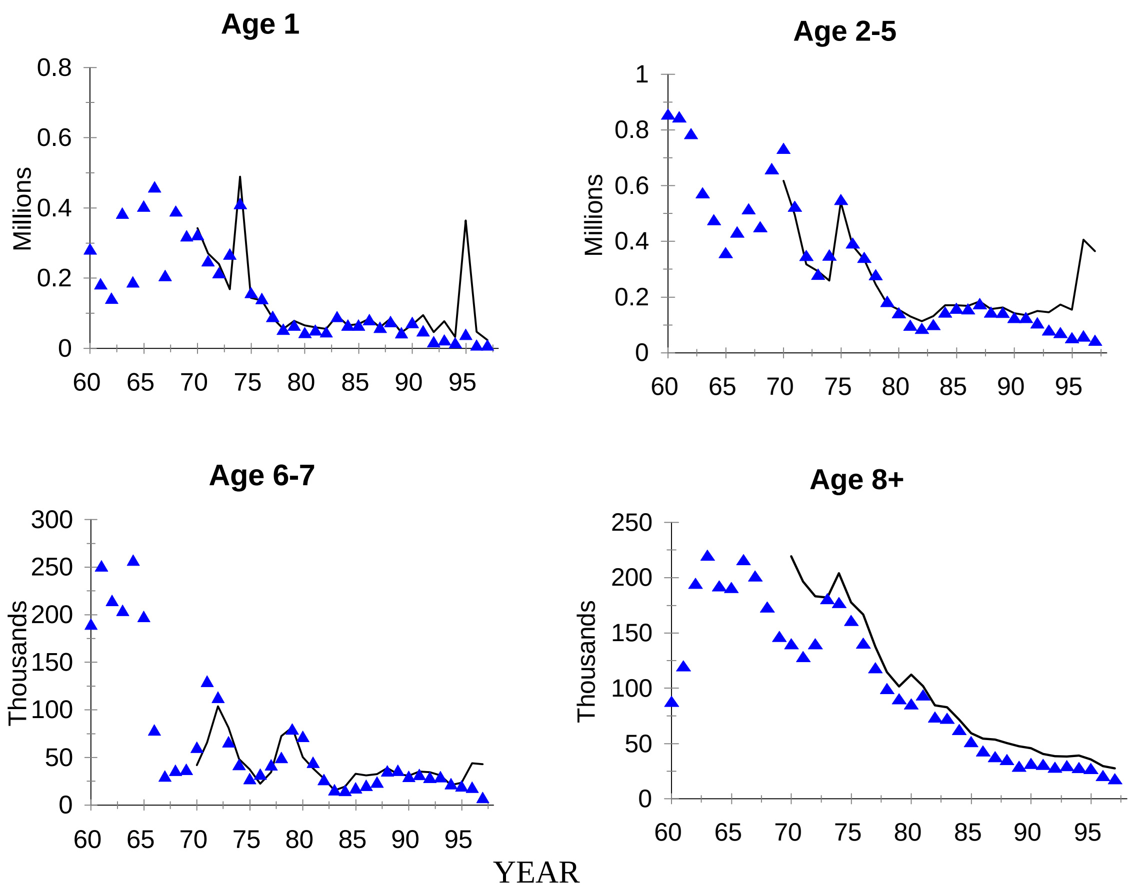


Figure 1. Estimates of historical abundances of West Atlantic bluefin tuna from program CATCHEM (triangles) compared with the corresponding SCRS estimates using ADAPT-VPA (lines). Note that the estimates for age 1 and ages 2-5 are highly uncertain during the last few years; the 1999 SCRS replaced those values based on the expected recruitment from a spawner-recruit curve.

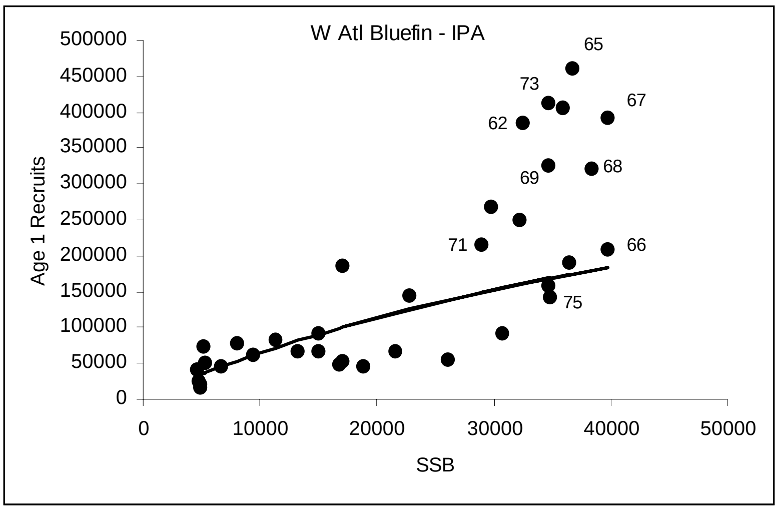
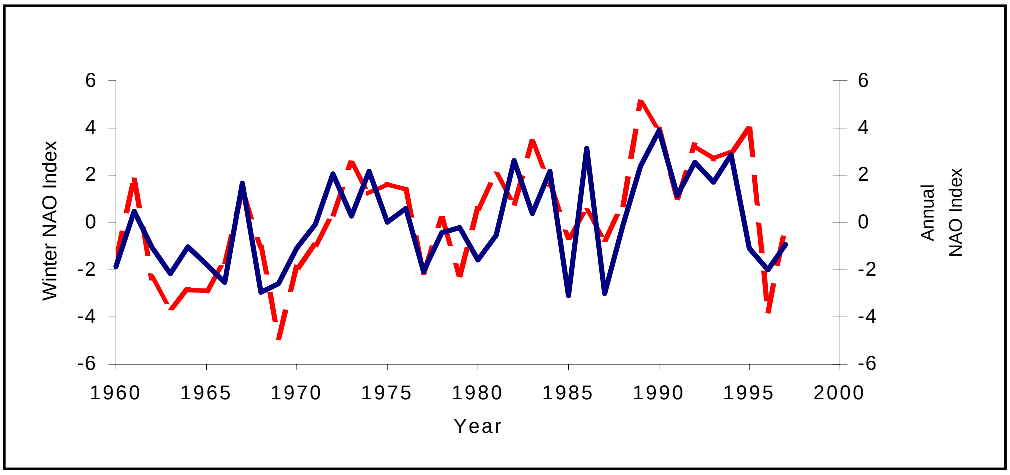


Figure 2. Estimated relationship of spawners to recruits from 1960 to 1997 with fitted Beverton and Holt curve.



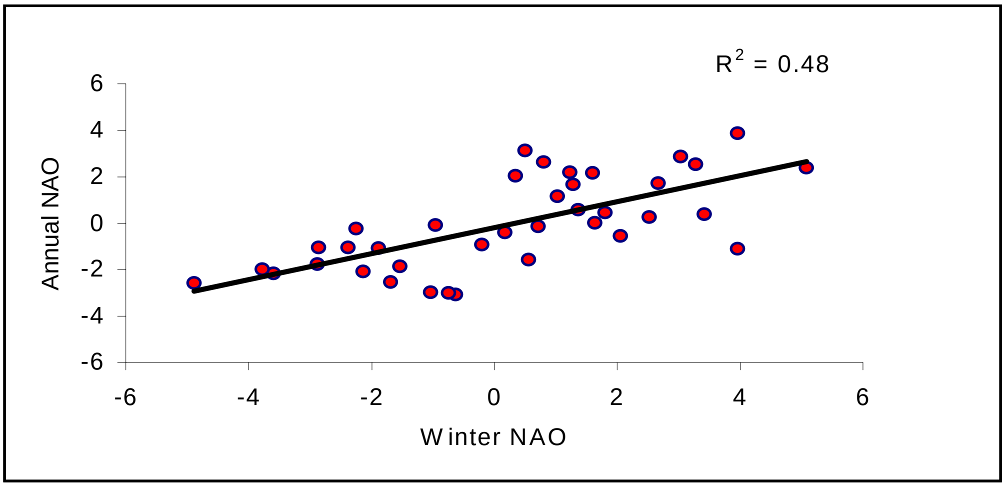
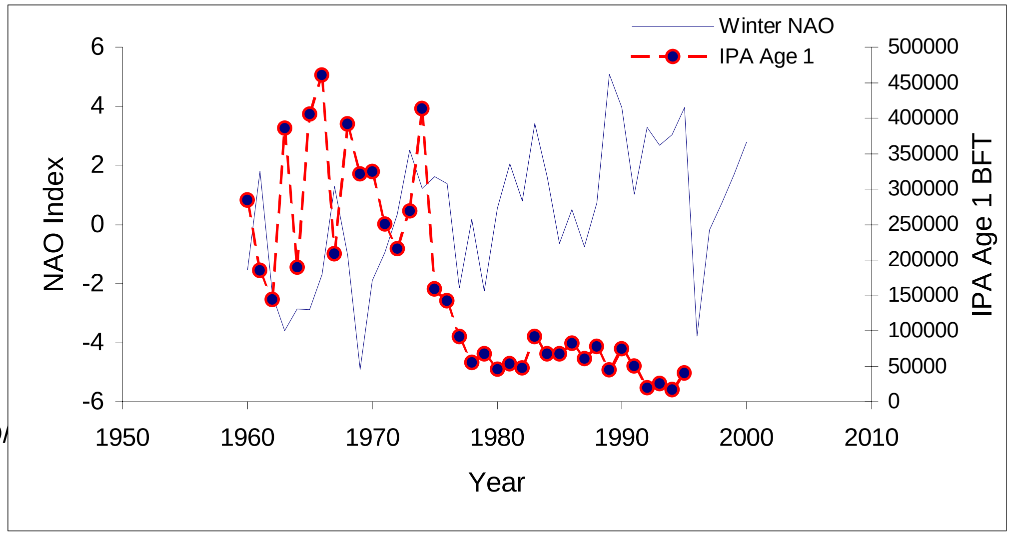


Figure 3. (Upper Plate) Annual (solid line) and Winter (dashed line, December through March) index of the NAO for 1960-1997 (using methods of Hurrell, J. W., 1995: Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science, 269, 676-679 and obtained from Hurrell's web sites cited below. Which for the winter index indicates the index calculations "are based on the difference of normalized sea level pressures (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland from 1864 through 1998. The SLP anomalies at each station were normalized by division of each seasonal pressure by the long-term (1864--1983) standard deviation. The station data were obtained from the World Monthly Surface Station Climatology . And for the Annual Index indicates Annual index of the NAO based on the difference of normalized sea level pressures (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik,Iceland from 1865 through 1997. The SLP anomalies at each station were normalized by division of each annual pressure by the long-term (1865--1984) standard deviation. The station data were obtained from the World Monthly Surface Station Climatology. www.cgd.ucar.edu/cas/climind/nao_winter.html and www.cgd.ucar.edu/cas/climind /nao_winter.html.

(Lower Plate) Correlation between winter and annual index values from the upper plate for the period 1960-1997.



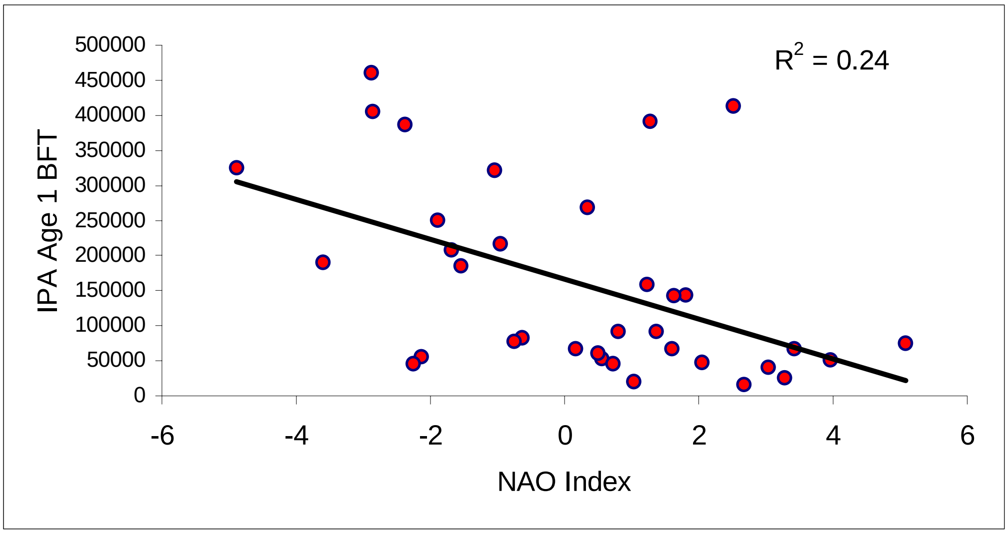
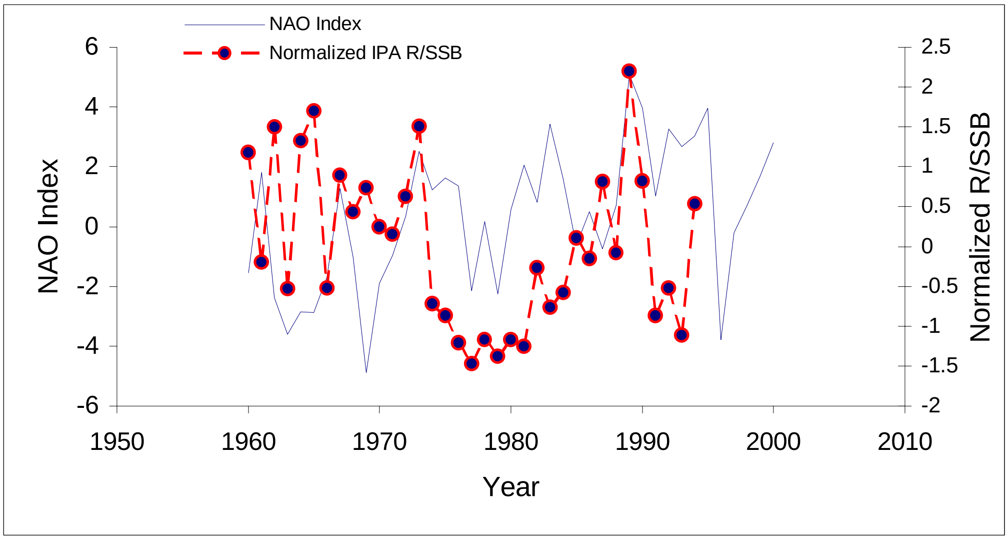


Figure 4. Upper plate, time-series comparison of estimated age 1 abundance and the winter NAO index. Lower plate, scatter plot of winter NAO against Age 1 estimated abundance (1 year lag) for year class strength estimates through 1995. Trend line and correlation are shown.



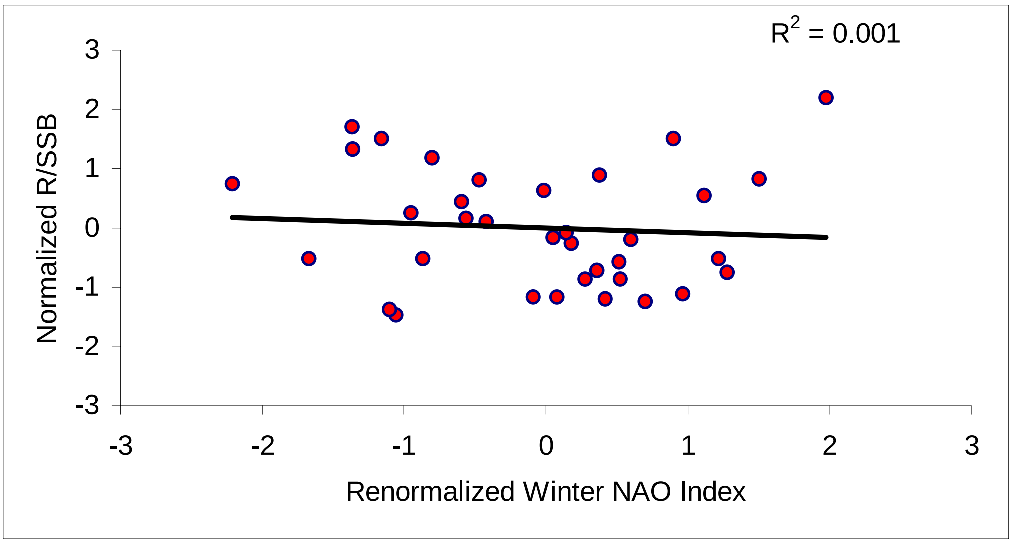


Figure 5. Upper plate, time-series comparison of estimated R/SSB and the winter NAO index. Lower plate, scatter plot of winter NAO against R/SSB. In both cases, the values were normalized [(Obs-Mean)/SD] for the period where paired observations were available. Trend line and correlation are shown.

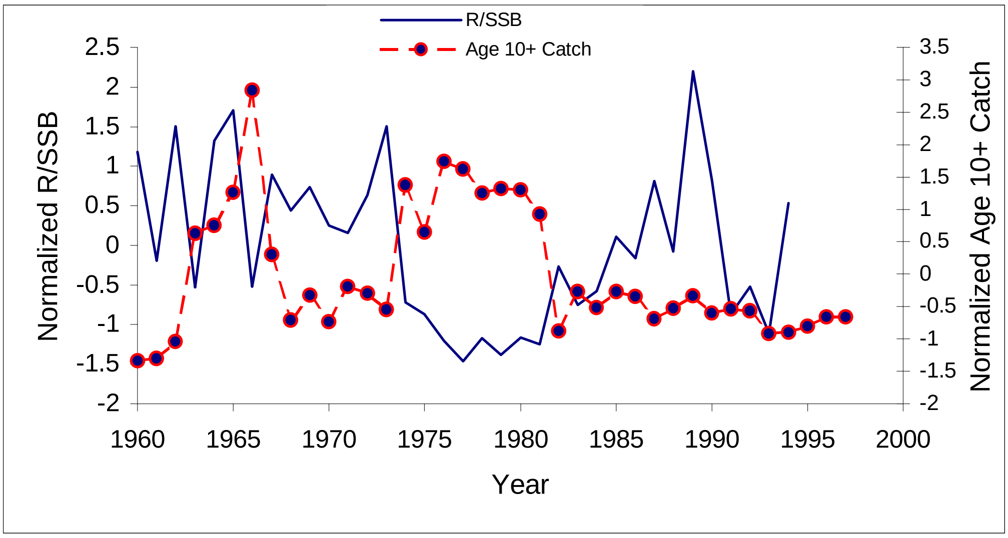


Figure 6. Time-series comparison of estimated R/SSB and the pattern in estimated age 10+ catch (numbers). In both cases, the values were normalized [(Obs-Mean)/SD] for the period where paired observations were available. Since the late 1960's, higher survival ratios are associated with lower relative catches of age 10+ bluefin while lower survival ratios are associated with higher relative catches of older bluefin.