TIME TRENDS IN ABUNDANCE AND CATCHABILITY OF YELLOWFIN TUNA AND THEIR RELATIONSHIP TO THE NORTH ATLANTIC OSCILLATION INDEX

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SUMMARY

This paper examines the correlation between biomass and catchability (q) of yellowfin tuna and the NAO index. Biomass estimates are obtained from a biomass dynamic model fitted to catch and cpue for the period 1950-1999. Several assessment scenarios are investigated. Scenarios are defined by the combination of indices used in the biomass dynamic model and the assumptions made about the variance of each index. Catchability trends are estimated by assuming that q varies according to a random walk with known variance.

No significant correlations were observed between the NAO index and either the yellowfin tuna biomass or with the catchability trends of any of the fleets. The only exception was the q for the US longline fleet that was correlated (r < -0.6) to the NAO index. This correlation is similar in magnitude to the ones detected for bluefin and swordfish. It is likely that these correlations, however, are the product of chance and do not necessarily evidence of forcing of recruitment by oceanographic processes.

RÉSUMÉ

Le présent document examine la corrélation entre la biomasse et la capturabilité (q) de l’albacore et l’indice NAO. Les estimations de la biomasse proviennent d’un modèle de dynamique de la biomasse ajusté à la capture et à la CPUE pour la période 1950-1999. Plusieurs scénarios d’évaluation sont étudiés. Les scénarios sont définis par la combinaison des indices utilisés dans le modèle de dynamique de la biomasse et des postulats formulés quant à la variance de chaque indice. La tendance de la capturabilité est estimée en supposant que q varie selon une évolution aléatoire sans variance connue.

Aucune corrélation significative n’a été observée entre l’indice NAO et, soit la biomasse de l’albacore, soit la tendance de la capturabilité des flottilles. La seule exception est le q de la flottille palangrière américaine qui était en corrélation avec l’indice NAO (r = -0.6). Cette corrélation est du même ordre de grandeur que celles qui ont été détectées pour le thon rouge et l’espadon. Il est probable, toutefois, que ces corrélations soient dues au hasard et ne constituent pas forcément des preuves de l’incidence des processus océanographiques sur le recrutement.

RESUMEN

Este documento examina la relación entre la biomasa y capturabilidad (q) del rabil y el índice NAO. Las estimaciones de biomasa se obtuvieron partiendo de un modelo de dinámica de biomasa adaptado a la captura y CPUE para el período 1950-1999. Se investigan varios escenarios de evaluación. Los escenarios se definen mediante la combinación de índices utilizados en el modelo de dinámica de biomasa y los supuestos sobre la varianza de cada índice. Las tendencias de capturabilidad se estiman suponiendo que q varía con un desarrollo aleatorio de varianza conocida.

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No se observaron relaciones significativas entre el índice NAO y la biomasa de rabil o las tendencias de captura de ninguna de las flotas. La única excepción fue la de la flota de palangre estadounidense que presenta una relación (<-0,6) con el índice NAO. Esta relación tiene una dimensión similar a las detectadas para el atún rojo y pez espada. Sin embargo, es probable que estas relaciones sean producto del azar y no prueben necesariamente la incidencia de los procesos oceanográficos en el reclutamiento.

**KEYWORDS**

Environmental effects, Climatic data, Catch statistics, catch/effort, mathematical models, simulation, assessment, stock assessment

1. INTRODUCTION

Fishery scientists continue to struggle to separate the effects that fishery harvests and environmental variability produce on fished populations. Most assessments consider environmental forcing as a random process that may affect the dynamics of stocks but that cannot be predicted or estimated from fisheries data. At most, assessments will include environmental variability as a source of uncertainty in the evaluation of past and future stock status. This limits the ability of fishery managers to deal with the consequences of environmental variability. The lack of predictability leads to a need to design management strategies that are conservative and robust to the random variation in population parameters induced by a changing environment. Although this policy agrees with the precautionary principle, it has an associated high cost, because it can demand very conservative (low) levels of harvest.

This situation has forced biologist and oceanographers to continue to try to detect and predict the links between oceanographic processes and fishery production. This must be done by first selecting the appropriate spatial and time scale, which is determined by the characteristics of the ecosystem that supports the fished stock. For large pelagic fish, such as tunas and billfish, which are not annual species and migrate over entire oceans, the choice of scale is obvious: the ocean basin and decadal fluctuations.

Links between the environment and populations of large pelagics have been described for temperate oceans. Santiago (1997) found that the Northern Atlantic Oscillation (NAO) was strongly negatively correlated with the recruitment of Northern Albacore and weakly positively correlated to that of eastern bluefin tuna. This correlation was observed for both one-year lag and no-lag. The NAO index explained 64% of the variability in recruitment of Northern Albacore. The NAO explains much less of the variability in eastern bluefin, 38%. A similar relationship to the one for albacore has been reported between the standardized cpue of Eastern Atlantic swordfish and the NAO index (J. Mejuto, I.E.O. personal communication). The NAO index explains in this case 33% of the variability in cpue and is also negatively correlated to the NAO. Fromentin et al. (2000) found oscillations in historical catches of Mediterranean bluefin tuna at frequencies of tens of years and proposes these are partially linked to oscillations of similar frequency in the environment.

In the tropical Atlantic the effects of environmental anomalies on tuna are less obvious but not always absent. Strong anomalies, such as the one seen in 1984 as a result of a strong "El Niño" in the Pacific, have been reported to be the cause of a sudden decrease in catches of yellowfin tuna in the purse seine fishery (ICCAT, 1998). A deeper thermocline and increased sea surface temperature (SST) may have affected yellowfin recruitment and purse seine catchability. Unfortunately it is difficult to conclude much from what may have happened in a single year, and it is better to examine the relationship between environment and the yellowfin tuna stock over the longest time period possible. This paper attempts to do just that by examining the correlation between population parameters for yellowfin tuna and indicators of climate.
1.1 The Atlantic yellowfin tuna and its environment

Yellowfin tuna is widely distributed in the tropical and sub-tropical oceans; it migrates across ocean basins and is captured by a variety of methods. In the Atlantic, it is harvested between 45° N and 40°S but the bulk of the catches is made by fleets operating inside the tropics, between 15° N and 15°S.

The exploitation of yellowfin in the Eastern Atlantic started in the early 1950s when artisanal baitboat and longline fleets started catching them in coastal areas. The purse seine fishery began in the mid 1960s. In the 1970s the purse seine and longline fleets expanded their fishing area by moving offshore into a wide equatorial area where yellowfin concentrate to spawn. Later, purse seine catches increased rapidly and became the main source of landings while catches of longliners decreased as these started targeting more bigeye tuna. Since the mid 1970s the activities of the purse seine fleet in the eastern area have been the dominant effect in the dynamics of the stock. In contrast, fisheries in the western Atlantic have developed much less.

In 1991 the purse seine fishery dramatically increased the number of floating objects used to attract tropical tunas. This also allowed this fishery to expand its fishing area westward.

Since 1994 (ICCAT, 1994) assessments have been done following the hypothesis that there is a single stock of Atlantic yellowfin tuna. This stock would have a main spawning area in the Eastern Equator and a nursery area in the Gulf of Guinea. Adults and juveniles are considered to move between both sides of the Atlantic. The spawning season is protracted but spawning clearly peaks during the first quarter of the year. Recruitment to the fishery mainly occurs in the last quarter of the year.

The seasonal to decadal climatic variability of the inter-tropical area, unlike the equivalent area in the Pacific, is not dominated by a single climatic process such as the El Niño Southern Oscillation (ENSO) (Ruiz-Barradas et al. 2000, Sutton et al. 2000). There is in fact disagreement on the extent of the connections in decadal climate variability between the tropical Atlantic, the Northern Atlantic and the Pacific. Some authors (Barradas et al. 2000) define, for the tropical Atlantic, two co-varying climatic modes they refer to as “Atlantic el Niño” and the “Interhemispheric mode” and suggest that both modes may be connected to ENSO. Rajagopalan (1998) for instance suggest that the interhemispheric mode may be partially affecting the North Atlantic and eventually the North Atlantic Oscillation (NAO). Other authors, however, maintain that the NAO drives tropical variability by equator-ward extension of northern climate variations (Xie and Tanimoto 1998, Sutton et al 2000, Robert Dixon, CEFAS, UK personal communication). Interestingly the dominant elements of climate variability observed in the tropical Atlantic seem to operate in different seasons. The connection to the NAO and ENSO seem to be stronger in the December to March period, whereas the rest of the year is dominated by tropical Atlantic modes (Sutton et al. 2000).

The fact remains that the tropical Atlantic suffers considerable climatic variability at basin scales that could be affecting the populations of yellowfin tuna and other tropical tunas. These effects can reflect the impact of oceanographic conditions on the survival but also on the availability of tuna to the fishing fleets. According to Fonteneau (pers. comm.) a deeper thermocline in 1984 decreased the availability of tunas for the purse seine fleet and lead to the migration of part of the purse seine fleet to the Indian Ocean.

2. METHODS

2.1 Data

Annual catch and catch per unit of fishing effort (cpue) data for Atlantic yellowfin tuna was obtained from ICCAT (ICCAT 2000). Five cpue indices were used: Spanish purse seine (1969-1999), French purse seine (1985-1999), Venezuelan purse seine (1987-1999), longline US (1982-1999) and
longline Japan (1975-1999). The French purse seine data for the period prior to 1985, although used by ICCAT (2000), was not used because of doubts about the values of the index (Olivier Maury, IRD, personal communication). Annual catch data was available for the period 1950 to 1999 (Table 1). NAO indices correspond to the December-March index, based on the normalized atmospheric pressure difference between Lisbon, Portugal, and Stykkisholmur, Iceland. We obtained these indices from the World Monthly Surface Station Climatology data set from the University Corporation for Atmospheric Research. An average NAO index was calculated as the mean value of the index in year $t$ and the four previous years. This average index takes into account the fact that, on average and at any given time, 5 age groups of yellowing tuna contribute to the catches of the fishery (Table 1).

2.2 Assessment model

To evaluate the status of yellowfin tuna stocks, we used the annual biomass dynamic model of Punt and Hilborn (1996),

$$B_{t+1} = B_t + g(B_t) - C_t$$

In this model $B_{t+1}$ and $B_t$ represent the biomass of the stock in two consecutive years $t$ and $t+1$; $g(B_t)$ is the growth in biomass function and $C_t$ is the total annual catch. Pallares et al (2000) showed that the results of yellowfin tuna assessments were not very sensitive to the type of growth in biomass function used although the results of the Schaefer model were more pessimistic than those from the Fox model. Therefore, for convenience and taking into account that we do not try to conduct a real yellowfin tuna stock assessment, we choose a $g(B_t)$ similar to the one used by Schaefer (1954) in his production model,

$$g(B_t) = r_t B_t \left(1 - \frac{B_t}{K_t}\right)$$

Unlike the traditional Schaefer (1954) model, we assume both $K_t$, the carrying capacity and $r_t$, the population growth rate, can vary with time $t$. In the most general case, the above model is, however, over-parameterized, and cannot be estimated. In order to fit the data we make the assumption that these parameters follow simple random walk models,

$$K_t = K_{t-1} \times \varepsilon_k \quad \text{where} \quad \varepsilon_k = N(0, \sigma_k)$$

$$r_t = r_{t-1} \times \varepsilon_r \quad \text{where} \quad \varepsilon_r = N(0, \sigma_r)$$

Because we do not have direct measures of biomass to fit the model, we use indices of abundance derived from commercial catch per unit of fishing effort. We assume that biomass and cpue are related as:

$$B_t = \frac{cpue_{q,i}}{q_{t,i}}$$

where $q_{t,i}$ is the catchability in year $t$ and for fleet $i$.

Catchability $q_{t,i}$ is also assumed to follow a random walk model with a linear increasing trend,

$$q_{t,i} = \alpha q_{t-1,i} \times \varepsilon_{q,i} \quad \text{where} \quad \varepsilon_{q,i} = N(0, \sigma_{q,i})$$

and where $\alpha$ is between 0 and 1.
Although, in theory, the biomass dynamic model with random walks in $K_t$, $r$, and $q_{t,i}$ is not over-parameterized, in practice, most data sets will not have enough contrast to be able to estimate all the parameters at the same time. We therefore choose to investigate scenarios where only one of the three parameters is a random variable, and the other two are held constant. In addition we investigate the possibility that there is no increasing trend in $q$ by setting scenarios were $\alpha = 0$.

2.3 Fitting procedures

To fit the data to the biomass dynamic model the FLSPM algorithm (available in EXCEL as part of the software known as FL) was used. This algorithm maximizes the likelihood function, given below, using the automatic differentiation library (AutoDiff) of Fournier, 1993.

$$-\ln(L) = \sum_i \left( \frac{n_i}{2} \sum_j \ln(\sigma_{ij}^2) + \sum_j \frac{1}{2\sigma_{ij}^2} (\hat{U}_{ij} - \hat{U}_{ij})^2 \right)$$

The last term is the sum of the squared differences between the observed and predicted indices of abundance (on the log scale where a lognormal error is assumed), and $\sigma_{ij}^2$ are the appropriate variances.

The expected indices are the stock sizes at the appropriate time of year times the catchability coefficient

$$\hat{U}_{iFleet,iYear} = q_{iFleet} B_{iYear}$$

Where $q_{iFleet}$ scales each index to absolute population size and their maximum likelihood values can either be obtained analytically or as part of the fitting algorithm.

The variances for each fleet can be obtained in several ways:

a) Equal weighting

If the values for all indices are given equal weight then they are calculated by

$$\sigma_{iFleet,iYear}^2 = \sum_{iFleet} \left[ \frac{1}{n_{iFleet}} \sum_{iYear} \left( \hat{U}_{iFleet,iYear} - \hat{U}_{iFleet,iYear} \right)^2 \right]$$

b) Maximum Likelihood Weighting

All values within an index have equal weights but each index is weighted depending on how it fits the model

$$\sigma_{iFleet,iYear}^2 = \frac{1}{n_{iFleet}} \sum_{iYear} \left( \hat{U}_{iFleet,iYear} - \hat{U}_{iFleet,iYear} \right)^2$$

c) Externally set

In this case the sigmas are input and correspond to some internal measure of uncertainty in the indices.
2.4 Assessment scenarios

In many assessments, where more than one index of abundance is used, different indices show contradictory patterns. If equal weights are given to all indices, often the fitting algorithm does not converge because it cannot reconcile the dynamics of the model to the various patterns associated with different indices. On the other hand when weights are allowed to vary the maximum likelihood solution tends to favor some indices and down-weight the importance of others so that their contribution to the likelihood is negligible. Although this solution could represent the best fit to the data it is highly likely that other solutions that use different combinations of indices may also be plausible. In order to investigate in a structured manner all these solutions we created all possible combinations of biomass indices and assumed that \( q_{t,i} \), \( K_t \) and \( r_t \) were constant with time. We then fitted the biomass model to all these combinations and allowed the statistical weights to be estimated. To evaluate the results of all these combinations we examined the residual patterns for all indices and the values of \( K \), \( MSY \), \( B_{msy} \) and \( B_{current} \). These solutions are referred to as assessment scenarios (Table 2).

2.5 Correlation with NAO

To estimate the effect of NAO indices we used time series analysis. We correlated the average NAO index to the residuals of the biomass dynamic model fits (logarithm of the ratio observed cpue / estimated cpue) and to the catchability trends for each fleet and for all the different assessment scenarios.

3. RESULTS

3.1 Assessment scenarios

In all the analyses we assume that the initial biomass (1950) was equal to the virgin biomass (K). If all five cpue indices were used and fitted to the biomass dynamic model, it was not possible to obtain a good fit to the model and estimate \( r \) and \( K \) together. To continue the analysis we fixed \( r \) to be 0.6.

Most combinations of cpue indices provided very similar estimates of \( K \) and MSY (Table 2). Only the scenario that used only the Japanese CPUE provided very different results. Estimates of current biomass varied much more than estimates of \( K \), and as a result the perception of the status of the stock \( (B_{current}/B_{msy}) \) varied as well. Disregarding those sets that only used Japanese cpue, it was interesting to see that small variations in the estimate of \( K \) resulted in large variation in the estimate of \( B_{current} \). This suggests that the productivity of the stock (\( K \) and MSY) is well defined by the data, but the current stock status is not. Closer examination shows that this is due to the fact that the assessment suggests that, in recent years, the stock has been depleted to levels where yield is relatively independent of stock size. This occurs in the area at the top of the equilibrium yield versus biomass curve. In this area yield changes little even if biomass changes dramatically. Thus unless cpue indices are precise it is very difficult for the production model to be able to determine where exactly in the biomass axis the current stock is. In general the inclusion of the cpue index of the Spanish purse seine fleet generated the most pessimistic results regarding the current rate of stock depletion (\( B_{1999}/K \)). Conversely, excluding the Japanese index, the French purse seine fleet index generated the most optimistic results.

Given the similarity of the results for many of the above scenarios for the final analyses only the following scenarios were retained:

- A. All. All indices and same statistical weight
- B. Best. All indices with weights determined through ML.
3.2 Trends in catchability

For scenario A, when all indices are allowed to have a random catchability the model fits all indices well and all residual patterns disappear. There is a strong pattern of increase (+ 12.5% per year) in q for the Japanese fleet from 1977-1989. Smaller increases in q were estimated for the French (5% per year) from 1985 to 1999. Decreases in q were estimated for the US longline for 1984-1991 (-4% per year), Spanish purse seine for 1985-1999 (-3% per year) and Venezuelan purse seine for 1987-1999 (-2% per year). There is also a period of a very large decrease in q over a short period (Spanish purse seine 1971-1974) and a period of a large increase over a short period (US longline 1996-1999). However the first period correspond to the beginning of this fishery when large changes in catchability may be expected. It is not possible to know whether any of these changes in q does represent true changes in catchability, however, it seems that the change estimated for the Japanese fishery is unlikely to be real because of its magnitude and its direction. During the late 1970s and 1980s, the shift from targeting yellowfin tuna to targeting bigeye, should have decreased the fishing power of Japanese longliners and not increased it.

Pattern in q for scenario B were similar to those estimated in scenario A, except for slight changes in the estimates of the Spanish purse seine fleet. When only one cpue index was used trends in q were similar for all indices except for the Spanish purse seine where q was found to be relatively constant except for decreases in 1984/85, 1991/92 and a 5% increase from 1992-1999.

3.3 Correlation with NAO

Correlations between NAO indices and the residuals of the biomass dynamic fit were small in all cases except for the US cpue. The residuals of the US cpue were negatively correlated with the NAO 5-year average index for all three scenarios (Table 3) with the correlation factor exceeding -0.63. This correlation is stronger after 1987 (Figure 3).

Similar results were obtained when catchability was allowed to vary randomly in the model. The catchability trends obtained were not correlated to the NAO indices except for the case of the US cpue where a negative correlation was obtained (Table 4, Figure 3).

4. DISCUSSION

The difficulty in determining stock status with a biomass dynamic model when the current stock is around Bmsy is a consequence of the fact that at around MSY yield changes little even if biomass changes substantially. Given the amount of uncertainty in abundance indices and in estimates of catch, to estimate the parameters that define stock productivity, MSY and Bmsy, with a biomass dynamic model it is necessary to deplete the stock below Bmsy. Unfortunately, this does not guarantee that current stock status can be accurately estimated. For that to happen the stock must be either strongly over-fished or, after being slightly overfished, have recovered to well above Bmsy. Only then will the parameters from the biomass model have the necessary accuracy properly determine the harvest controls required to reach the target biomass.

Our analyses suggest that the status of the yellowfin tuna stock is around Bmsy so that its productivity is reasonably well defined by the estimates derived from the biomass dynamic model. The exact status of the stock, the ratio of current biomass to the biomass at MSY is, however, not well defined. This uncertainty exists because the stock seems to be hovering at just below Bmsy and from the fact that some of the abundance indices provide conflicting signals.

The Spanish purse seine cpue index was developed by partially correcting for changes in the fleet and thus in fishing power. That may explain why in comparison to other indices it suggests a more pessimistic view of the stock. Similarly indices for the eastern part of the fishery tend to give more pessimistic views than those for the western part. This may be related to the different components of the stock that the corresponding fleets are harvesting. Eastern fleets harvest a larger proportion of
young individuals than the western fleets, therefore their cpue indices may reflect more the biomass of recruits than western indices and thus western indices may have a lag of a few years in comparison to eastern indices. On the other hand, if mixing through the Atlantic is not intense enough to completely balance differential fishing impacts in both sides it could be that biomass in the west remains proportionally greater than that in the east.

It is unclear why the Japanese longline cpue index shows such a different trend from all other indices. This difference is greatest during the period from 1980 to 1992, when the Japanese cpue index first doubles and then it halves. This period coincides with the years where there was a shift from east to west in the distribution of yellowfin tuna catches of the Japanese fleet. This index, however, was obtained with a GLM containing area thus the standardization process should have removed the possible effect of the shift in distribution.

This uncertainty in the estimates of current biomass does not necessarily translate into an uncertain historical biomass pattern. Most of the assessments, with the exception of the one that uses only the Japanese biomass index estimate a very similar pattern of biomass change. This is reflected in the fact that the patterns of cpue residuals for the different scenarios are similar. As a result the correlations with the climate index do not vary much between scenarios.

The amount of variance in recruitment of northern albacore (64%) explained by the NAO index (Santiago 1996) is substantially greater than any of the variance in residual cpue or catchability of yellowfin tuna explained by the NAO indices. The estimated correlation found between the 5-year average NAO index and either the US cpue residual or the US catchability explains a similar percentage of variance than that reported by Santiago for eastern bluefin tuna (38%). It is entirely possible that such correlations are the product of chance, and do not indicate any direct connection between biomass of tuna and climate. This is specially likely when one correlates a large number of indices as it was done in this paper.

In addition, one must keep in mind the historical range of observations. During the 1900s the NAO showed a very clear multidecadal trend. For the first sixty years the NAO index tended to decrease, whereas for the other forty years it tended to increase. Given that most fishery time series correspond to the period after 1960, one can expect that any time series with a clear trend (increasing or decreasing) from 1960 will be correlated to the NAO index. This could easily explain the correlations detected between NAO and eastern bluefin, eastern swordfish and now yellowfin tuna abundance and catchability for the US part of the stock.

The correlation estimated by Santiago (1998) for northern albacore, however, goes beyond this trend, in fact it seems that the three cycles observed in the NAO index, with peaks in early the 1970s, 1980s and 1990s, are mirrored by three similar cycles of recruitment in northern albacore. One must conclude therefore that northern albacore recruitment seems to be the only biomass index for Atlantic tunas that could be said to unequivocally follow the same pattern as the NAO index.

So why would only albacore would respond to changes in the environment? The easiest answer is to say that albacore has the northernmost distribution of all tunas and thus is likely to be most affected by the NAO, which is a north Atlantic climatic phenomenon. On the other hand positive NAO indices coincide with the strengthening of the easterly equatorial trade winds (Ruiz-Barradas et al 2000, B. Dickson CEFAS, personal communication) and with lower SSTs in the eastern equatorial Atlantic. There are also references indicating that these changes are associated with corresponding changes in the oceanography of the southeastern Caribbean and the Northwestern Gulf of Mexico, thus one may argue that the effects of NAO extend to all the area of distribution of yellowfin tuna.

The estimated trends in catchability from this study do not completely coincide with those estimated by ICCAT with a multifleet production model (ICCAT 2000). The patterns estimated for the Spanish, Venezuelan and US indices are similar in both studies. The patterns estimated for the Japanese and French index differ substantially. Our study suggests catchability changed much more in
the Japanese fishery than that estimated by the multifleet model. Also, in our study catchability substantially decreased for the French fleet up to the mid 1980s, whereas in the ICCAT study it increased. These differences can be partially explained by differences in the models. The multifleet model uses information on effort to calculate fishing mortality and then adjusts catchability so that the observed catch approximates the product of fishing effort and cpue. Our model makes no such assumption. It is worth noting that ICCAT (2000) point out that the multifleet model does not fit the Japanese fishing mortality as well as it does for the other fleets. On the other hand both our model, and the multifleet model and biomass dynamic model of ICCAT lead to very similar estimates of MSY, K and current biomass.

It is also interesting that catchability estimates for yellowfin tuna are not correlated with the NAO index. It has known that water temperature partially explains the distribution and thus availability of tunas, being sometimes correlated to their catchability. The NAO and q indices used here, however, are integrated over a year and a large part of the Atlantic, whilst most processes that explain a relationship between water temperature and tuna distribution operate over much smaller spatial (fronts) and time (days) scales. Similarly strong winds are known to impede the operations of purse seiners, however, such alterations are also likely to be important only at small time scales (days).

In summary, this paper shows that there is no clear evidence that the NAO index can be used to understand the unexplained variation in yellowfin tuna biomass or catchability. The paper also shows that there is substantial uncertainty in the current status of yellowfin tuna, regardless of the number of abundance indices used. It does seem to confirm earlier assessments made (ICCAT, 2000) that suggest the stock is likely to be at B_{msy}.

REFERENCES


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Table 1: Catch, cpue indices and NAO index data used in analyses.

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Table 2: Biomass dynamic parameter estimates for different assessment scenarios where + indicates inclusion of a given cpue index (Sp = Spain, Fr = France, Ve = Venezuela, US = United States and Ja = Japan). K is the carrying capacity, B is biomass and L the negative log likelihood. All quantities are in thousands of tons.

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Table 3: Correlation between NAO indices (yearly and 5-year average) and residual cpue from the different assessment scenarios.

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B) All indices used, weights determined by maximum likelihood

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S) Only one index used at a time

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Table 4: Correlation between NAO indices (yearly and 5-year average) and catchability estimates from the different assessment scenarios.

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B) All indices used, weights determined by maximum likelihood

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<td>NOAV</td>
<td>-0.074</td>
<td>-0.125</td>
<td>-0.067</td>
<td>-0.522</td>
<td>0.507</td>
</tr>
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Figure 1. Example of fit to biomass model. Scenario with no time trend in catchability and all cpue indices used. Statistical weights for all indices equal.
Figure 2: Trends in catchability estimated for biomass dynamic model for scenario A, where all cpue indices were used and given the same weight.
Figure 3: Historical trends in the 5-year average NAO index, the residual cpue for the US fishery and the catchability for the US fishery. Residual cpue and catchability were obtained from assessment scenario A, where all cpue indices are used and given equal weight. Residual cpue correspond to a scenario with constant $q$. 