

STOCK ASSESSMENT AND RISK ANALYSIS FOR THE SOUTH ATLANTIC POPULATION OF ALBACORE (*THUNNUS ALALUNGA*) FOR 1994

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ABSTRACT

The south Atlantic population of albacore is assessed by means of an age-structured production-model using Taiwanese and Japanese catch rate data up to 1992. Risk Analysis calculations are carried out for a variety of future catch trajectories. The resource is estimated to be markedly depleted - to probably less than 20% of its pre-exploitation level expressed in terms of exploitable biomass - and to have an MSY slightly in excess of 25,000t p.a. This analysis indicates that recent average annual catches of some 28,600t need to be reduced below 25,000t to prevent continued depletion of the resource in the long term. Careful monitoring of the situation is required to allow refinement of these estimates with time, and to check the effectiveness of any management action taken.

RESUME

La population de germon de l'Atlantique Sud est évaluée par un modèle de production structuré par âge qui utilise les données sur les taux de capture du Japon et de Taïwan jusqu'en 1992. Des calculs d'analyse de risque sont effectués pour diverses trajectoires futures de capture. On estime que cette ressource est fortement épuisée - à probablement moins de 20% de son niveau de pré-exploitation exprimé en termes de biomasse exploitable - et que sa PME dépasse légèrement 25.000 p.a. Cette analyse indique que les prises annuelles moyennes récentes d'environ 28.600 TM doivent être réduites à un niveau inférieur à 25.000 TM pour empêcher l'épuisement continu de la ressource à long terme. Un suivi attentif de la situation est indispensable pour permettre l'affinement de ces estimations avec le temps et pour vérifier l'efficacité de toute mesure de gestion qui est prise.

RESUMEN

Se evalúa la población de atún blanco del Atlántico sur por medio de un modelo de producción estructurado por edad, usando datos de tasa de captura taiwaneses y japoneses hasta el año 1992. Se hacen cálculos de análisis de riesgo para una variedad de trayectorias futuras de captura. Se estima que el recurso está muy decimado - hasta probablemente menos del 20% de su nivel anterior a la explotación expresado en términos de biomasa explotable - y que tiene un RMS ligeramente superior a 25.000 t p.a. Este análisis indica que la media anual reciente de capturas, unas 28.600 t, debe reducirse hasta menos de 25.000 t, con el fin de prevenir que el recurso continúe siendo decimado a largo plazo. Es necesario observar cuidadosamente la situación con el fin de refinar estas estimaciones y comprobar la eficacia de cualquier acción emprendida en cuestión de ordenación.

1. INTRODUCTION

The fishery for albacore (*Thunnus alalunga*) in the south Atlantic commenced in the late 1950's. Catches increased steadily and have, since 1964, exceeded 20,000t in most years (Table 1, Figure 1). The two largest catches were recorded in 1986 and 1987 (36,200 and 39,800t respectively). The bulk of the catch from this stock has been taken by the Taiwanese longline fleet, although the catches by the South African baitboat fishery (Penney *et al.* 1992) are becoming notable.

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Prior to 1992, assessments of this stock were based on the effort-averaging estimator developed by Fox (1975) (e.g. Yeh *et al.* 1991, 1992). This approach suggests that the resource is currently "fully-exploited" and that *MSY* is 26-27,000t (ICCAT 1993). Effort-averaging estimation methods have been severely criticized in the literature (e.g. Sissenwine 1978; Roff and Fairbairn 1980; Butterworth and Andrew 1984; Punt 1988; Polacheck *et al.* 1993). Butterworth and Andrew (1984) and Punt (1988, 1993), for example, demonstrate that these methods lead to severely positively biased estimates of *MSY* and optimal effort when applied to *CPUE* series which decline over time. Punt *et al.* (1992) applies dynamic production-model and age-structured production-model estimation approaches to the catch and the Taiwanese catch-rate data for the south Atlantic albacore resource, and concludes that *MSY* is less than 25,000t and that the current replacement yield (the catch which will leave the biomass at its current size) is of similar magnitude.

Punt *et al.* (1996a) updates the age-structured production-model assessments of Punt *et al.* (1992) using the then most recent data, and estimates *MSY* to be slightly in excess of 20,000t. Based on risk analyses, that paper suggests that catches need to be reduced to at least 20,000t. Punt *et al.* (1996b) conducts a further stock assessment update using Japanese catch-rate data in addition to Taiwanese catch-rate data, and concludes that the stock of south Atlantic albacore is currently slightly above the level at which *MSY* is achieved, although catches currently exceed the estimate of *MSY*. Punt *et al.* (1996c) examines the sensitivity of abundance indices derived using the Taiwanese longline catch-rate data to various alternative GLM techniques. This paper updates the assessment of Punt *et al.* (1996b) using these revised Taiwanese abundance indices, and examines the consequences of various possible candidate management measures by means of Risk Analysis techniques.

2. STOCK ASSESSMENT

2.1 Methodology

Assessments of the stock of albacore in the north Atlantic (e.g. ICCAT 1991, 1993, 1994) have been carried out using *ad hoc* tuned VPA (e.g. Pope and Shepherd 1985; Butterworth *et al.* 1990) and ADAPT (Gavaris 1988), although, in principle, the statistically more defensible Integrated Analysis (e.g. Deriso *et al.* 1985; Lewy 1988; Kimura 1990) could have been used instead. Unfortunately, it is impossible to apply any of these assessment techniques to south Atlantic albacore because of the lack of reliable estimates of the age-composition of the historic catches.

It is therefore necessary to utilize an assessment technique which does not require estimates of the age-composition of the catches. The most obvious candidates are surplus production models (e.g. Schaefer 1954, 1957). Standard surplus production models (e.g. Schnute 1977; Butterworth and Andrew 1984; Leonart *et al.* 1985) treat the resource biomass as a lumped variable and therefore do not take direct account of the underlying age-structure. In contrast, the method used here does take direct account of the age-structure of the population (Punt *et al.* 1992). It replaces estimation of the parameters of the surplus production function (e.g. *r* and *K* of the Schaefer model) by estimation of the parameters of a stock-recruitment relationship. The procedure differs from VPA, Integrated Analysis and ADAPT in that recruitment is assumed to be functionally dependent on spawner stock size, and catch-at-age data need not be used in the model-fitting process. The model and its associated estimation procedure are detailed in Appendix B, and the approach used to estimate the standard errors of the estimated quantities is given in Appendix C of Punt *et al.* (1996b).

2.2 The base-case specification of parameter values

The base-case values of the parameters of the model have been set according to the specifications in ICCAT (1994).

- a) Natural mortality is assumed to be equal to 0.3yr^{-1} for ages 0 to 12, and infinite thereafter (i.e. fish are assumed not to live beyond their thirteenth year of life, so that the plus-group for which allowance is made in the model used (Appendix B, Punt *et al.* 1996b) does not come into play).
- b) The mass in gm (*w*) of a fish of age *a* in years (length *L* in cm) has been specified using the growth curve of Lee and Yeh (1993) and the length-mass relationship of Penney (1994):

$$L_a = 142.28(1 - e^{-0.1434(a-0.672)}) \quad (1)$$

and

$$w = 1.3718 \times 10^{-5} L^{3.0973} \quad (2)$$

c) The fecundity schedule is given by:

$$f_a = \begin{cases} 0 & \text{if } a < 6 \\ 1 & \text{if } a \geq 6 \end{cases} \quad (3)$$

A further assumption is that the selectivity of the entire fishery is the same as that of the Taiwanese fleet, and follows a logistic curve with a length-at-50%-selectivity of 80cm, (corresponding to an age of 6.4yr), and a width parameter δ assumed to be 0.2yr, so that:

$$S_{y,a} = (S_a^e)^1 = \frac{1}{1 + e^{-(a-6.4)/0.2}} \quad (4)$$

where the *CPUE* series index $i=1$ refers to the series for the Taiwanese fleet.

2.3 Data utilized

The catch-by-mass data for the entire fishery (all fleets and gears combined) for the period 1957-1992 are listed in Table 1. This Table also lists the Taiwanese and Japanese abundance indices used in the model fitting process. Three abundance indices are provided for the Taiwanese longline fleet to examine the sensitivity of the results to the method used to conduct the standardization of the catch-rate data for this fleet (see Punt *et al.* (1996c) for details). The first of these indices (GLM 1) forms the base-case for the analyses of this paper. This base-case application involves using the three Japanese indices in addition to the GLM 1 index. The sensitivity of the assessment results to replacing the GLM 1 index by the other two Taiwanese indices in turn (acronyms "With GLM 4" and "With GLM 7"), to using only the Taiwanese indices (acronyms "GLM 1 only", "GLM 4 only" and "GLM 7 only"), and to using only the Taiwanese indices but also leaving out the data points for 1968 and 1969 which appear to be outliers (see Figure 4 of Punt *et al.* (1996c)) (acronyms "GLM 1 only less 68/69", "GLM 4 only less 68/69", "GLM 7 only less 68/69") is investigated.

The age-structured production-model approach requires that selectivity patterns be specified for all of the abundance indices considered in an analysis. As suggested by ICCAT (1994), the length-at-50%-selectivity for the early (1959-1969) Japanese index is taken to be 100cm (corresponding to an age-at-50%-selectivity of 9.0 yr), while for the remaining indices it is assumed to be 80cm. The selectivity functions are all assumed to have the logistic form, and the width parameter (see Equation 4) is taken to be 0.2 throughout.

2.4 Further sensitivity tests

Three additional applications of this stock assessment technique have been carried out to assess the sensitivity of the results to other sources of uncertainty (acronyms in parenthesis).

- a) $M=0.2\text{yr}^{-1}$ instead of 0.3yr^{-1} ($M=0.2\text{yr}^{-1}$).
- b) $M=0.4\text{yr}^{-1}$ instead of 0.3yr^{-1} ($M=0.4\text{yr}^{-1}$).
- c) The Beverton-Holt form of the stock-recruitment relationship is replaced by the Ricker form (Ricker).

Punt *et al.* (1992, 1996a, 1996b) examined the sensitivity of their assessment results to changing the selectivity pattern and to varying the growth curve and the length-mass relationship. Such examinations are not conducted here because those previous studies found that the assessment results are insensitive to such modifications.

The variance estimation procedure described in Appendix C of Punt *et al.* (1996b) (henceforth referred to as the "standard" variance estimation procedure) is based on the assumption that the age-specific selectivity pattern is known without error. To assess the sensitivity of variance estimates to this assumption, an alternative method of variance estimation has been implemented for the base-case application. This alternative (acronym "with selectivity variance") involves generating noise about the pattern assumed as follows:

$$S_{y,a} = S_a^e e^{\Phi_{y,a}} \quad \Phi_{y,a} \sim N(0, 0.2^2) \quad (5)$$

where $N(0,0.2^2)$ is a normal distribution with mean zero and standard deviation 0.2. On each occasion that the model is fitted to a bootstrap replicate data set, the deterministic selectivity pattern is replaced by an annually changing stochastic realization provided by Equation (5). The choice of 0.2 for the CV of the fluctuations about the assumed age-specific selectivity pattern is essentially arbitrary, and is based on the selection made by Punt (1992b) for analyses involving Cape hake.

2.5 Results and discussion - base-case application

Table 2 contains the base-case estimates of eight management-related quantities, their CVs and 90% confidence intervals (results are shown for both the "standard" and "with selectivity variance" variance estimation procedures). These eight quantities are:

- | | |
|-----------------------|---|
| a) MSY | the maximum sustainable yield, |
| b) TAC_{sq} | the $F_{status-quo}$ harvesting strategy TAC for 1993, |
| c) $RY(93)$ | the 1993 replacement yield, |
| d) B_{1992} | the (exploitable) biomass in the middle of 1992, |
| e) B_{1992}/K | the (exploitable) biomass in the middle of 1992 as a fraction of the corresponding pre-exploitation equilibrium biomass, |
| f) B_{1992}/B_{MSY} | the (exploitable) biomass in the middle of 1992 as a fraction of the corresponding equilibrium biomass at which MSY is achieved, |
| g) Steepness | the "steepness" of the stock-recruitment relationship (i.e. the fraction of virgin recruitment to be expected when the population is reduced to 20% of its pre-exploitation equilibrium level), and |
| h) F_{1992}/F_{MSY} | the fishing mortality during 1992 as a fraction of that at which MSY is achieved. |

Figure 2 plots the actual and model-predicted CPUE series for the base-case analysis and Figure 3 shows the exploitable biomass time series (both in absolute terms and as a fraction of the corresponding pre-exploitation equilibrium level) for six different choices for CPUE data input.

There are no obvious indications of model mis-specification in Figure 2, although the fits to the two early Japanese indices are poor. The estimate of MSY (25,200t) is lower than any of the catches since 1984, and the model indicates that catches have consistently exceeded replacement yields since 1985, with the consequence that the biomass has been dropping over this period (Figure 3). This is also reflected in the estimate of the fishing mortality for 1992 which is almost 20% larger than that required to achieve MSY (Table 2). The resource is estimated to be at the size at which MSY is achieved (B_{1992} is 101% of B_{MSY}) but this result must be considered in the context that B_{MSY} is estimated to be very small (0.15). Indeed, the current exploitable biomass is estimated to be only 15% of its pre-exploitation equilibrium level (i.e. below the level of 20% often considered to be a threshold "below which one does not want to go" (e.g. Bergh and Butterworth 1987; Francis 1992; Butterworth and Bergh 1993).

The current replacement yield is estimated to be 26,000t which is larger than the estimate of MSY . This is a consequence of transient age-structure effects, and catches of this magnitude cannot be sustained in the medium to long-term. The steepness of the stock-recruitment relationship is 0.88, which is consistent with the perception (ICCAT 1994) that recruitment of albacore is independent of spawner stock size unless this size is reduced to very low levels.

The values for MSY , the $F_{status-quo}$ strategy TAC for 1993, $RY(93)$ and B_{1992}/K are estimated fairly precisely ("standard" and "with selectivity variance" method CVs of roughly 20% or less) while those of B_{1992} , B_{1992}/B_{MSY} and particularly F_{1992}/F_{MSY} are rather imprecise. The "standard" and "with selectivity variance" method CVs are very similar for most quantities, suggesting that random fluctuation about the assumed age-specific selectivity pattern (at the level considered) does not have a major impact on estimation precision for this stock. The "standard" method CV for the $F_{status-quo}$ strategy TAC for 1993 seems unrealistically low compared to the CVs for the other quantities. This is probably because temporal fluctuations in selectivity are ignored by this method - this CV increases from 1.5% to 7.5% when this source of variability is taken into account.

2.6 Results and discussion - sensitivity tests

Qualitatively, the results are insensitive to the selection of abundance indices used when fitting the model, the form of the stock-recruitment relationship and the value of natural mortality (Table 3). The most optimistic appraisal (in terms of the B_{1992}/B_{MSY} ratio) is that in which the Taiwanese GLM 1 index is replaced by the Taiwanese GLM 7 index (Table 3 - "With GLM 7"). Markedly more pessimistic appraisals occur when the Japanese indices are omitted from

the analyses. The estimates of current depletion (i.e. B_{1992}/K) range from 0.081 (GLM 7 only) to 0.210 (With GLM 4). The estimate of current replacement yield ranges from 20,700 (GLM 4 only) to 27,000t (With GLM 7), and the MSY estimates range from 17,900 (GLM 4 only) to 27,100t (With GLM 7). The estimate of the ratio of 1992 fishing mortality to that at which MSY is achieved exceeds unity for all of the tests conducted. The estimates of steepness for some of the sensitivity tests (e.g. GLM 4 only) seem surprisingly low for a species such as albacore.

Sinclair *et al.* (1990) note that many stock assessments exhibit "retrospective patterns" (i.e. the point estimates of some population parameters or variables change systematically over time as new data are incorporated into the assessment). In order to examine whether this is the case for this assessment, the age-structured production-model approach was applied to a range of data sets, each with the base-case specifications but differing in the final year in the assessment. Figure 4 shows the estimated exploitable biomass time series for each of these applications. The results in Figure 4 are not indicative of substantial differences between assessments with different final years, which suggests that retrospective patterns are not a major issue for this assessment.

3. RISK ANALYSIS

3.1 Methodology

Four Risk Analysis variants of increasing complexity are considered here. The differences between the four relate to the distribution of numbers-at-age at the start of the projections (either the "best fit" values or the results of the bootstrap calculations) and whether future recruitment and selectivity fluctuations are taken into account when projecting the model forward in time. The four options (all of which relate to the base-case assessment) are as follows.

- a) All projections start from the "best fit" estimates of the numbers-at-age at the start of 1993 - future recruitment is deterministic and there are no fluctuations in selectivity-at-age.
- b) As in a), except that future recruitment is log-normally distributed about its expected value - the CV of the log-normal distribution is 0.4 [the standard deviation of the natural logarithms of the ADAPT recruitment estimates for the north Atlantic stock of albacore is 0.2, and is 0.5 for the corresponding *ad hoc* tuned VPA (ICCAT 1993) - the choice of 0.4 amounts to taking the average of the two associated variances]. A total of 1000 simulations are carried out to calculate the performance indices.
- c) As in b), except that future selectivity-at-age is log-normally distributed about its expected value for each age and year - the CV of the log-normal distribution is 0.2.
- d) Projections are carried out from each of the 500 "with selectivity variance" bootstrap numbers-at-age vectors for the start of 1993 (with 10 projections for each such vector) - recruitment is log-normally distributed with a CV of 0.4 and selectivity-at-age is log-normally with a CV of 0.2.

3.2 Performance indices

The six performance indices considered are as follows:

- i) Av Catch - the average catch over the projection period considered.
- ii) $E(B_{fn}/B_{MSY})$ - the average ratio of the exploitable biomass at the end of the projection period to the corresponding biomass at which MSY is achieved.
- iii) $P(B_{fn} > B_{MSY})$ - the probability that the exploitable biomass will exceed that corresponding to MSY at the end of the projection period.
- iv) $P(B_{fn} > B_{1992})$ - the probability that the exploitable biomass will exceed the current biomass at the end of the projection period.
- v) $E(B_{fn}/K)$ - the average ratio of the exploitable biomass at the end of the projection period to the corresponding pre-exploitation equilibrium level.
- vi) $5\%(B_{fn}/K)$ - the lower 5%-ile of the distribution of the ratio of the exploitable biomass at the end of the projection period to the corresponding pre-exploitation equilibrium level.

3.3 Future catch trajectories

The various future catch trajectories considered are listed in Table 4. Although the assessment goes no further than the start of 1993, (almost) two further years have already passed. The choice of catches of 28,600t for both of these years (1993 and 1994) for all the trajectories assumes that these catches will not have deviated markedly from the average catch over the preceding three years.

The first catch trajectory considered (A) corresponds essentially to an absence of future management restrictions, with the allied assumption that annual catches remain unchanged. The other four catch trajectories in Table 4 all reflect some future catch limitations. Catch trajectories B, C and D impose a 28,600t catch limitation for 1995 and reduce this limitation in 1996. The three alternative constant catches imposed from 1996 onwards (25,000t, 23,000t and 20,000t) were selected to achieve an exploitable biomass in 2002 which is similar to that during 1996 (Figure 5). The purpose of examining catch trajectory E is to illustrate impact of implementing increasingly severe catch restrictions over a period of time.

3.4 Results and discussion

The results of the fully-deterministic projections [i.e. Risk Analysis method (a)] for the various future catch trajectories of Table 4 are illustrated in Figure 5. The associated performance indices are reported in Table 5 for 5- and for 10-year projection periods. Table 6 gives corresponding results for the fully-stochastic analyses [i.e. Risk Analysis method (d)], and Table 7 compares results from the four Risk Analysis methods for catch trajectory C.

The projections shown in Figure 5 have qualitative features which are hardly unexpected, given the estimates for *MSY* and stock status reported in Tables 2 and 3. Catch trajectory A, reflecting an unchanged level of catch under an absence of restrictions, leads to virtual extinction of the resource by the end of the decade (by 1997, it is no longer possible to achieve a catch of 28,600t as the fishing mortality on fully-selected age-classes reaches the maximum value permitted in the computations of 3yr^{-1}). Certainly the enactment of management measures to effect, at minimum, the sustainability indicated for trajectory B (a *TAC* set at 25,000t from 1996 onwards) appears to be an urgent priority.

4. CONCLUSIONS

The assessments of this paper indicate once again that the south Atlantic albacore resource has been markedly reduced by harvesting. The current level of the exploitable biomass is estimated fairly robustly to be less than 20% of its pre-exploitation level. *MSY* is estimated to be roughly 25,000t p.a., which is substantially less than the average of recent annual catches which approaches 29,000t.

Risk Analysis, in the form of 10-year projections under alternative series of future catches, suggests that the decline of the resource will continue unless catches are restricted to less than 25,000t from 1996 (assuming a 1995 catch of 28,600t). Even in this situation, continued decline is not improbable, so that careful monitoring would be essential to check whether further catch reductions would be needed in subsequent years.

Table 1: Catch and abundance index information for the population of albacore in the south Atlantic

Year	Catch '000	Taiwanese			Japanese		
		GLM 1	GLM 4	GLM 7	1959-69	1969-75	1975-92
1957	0.7						
1958	1.0						
1959	4.8				394.713		
1960	10.5				315.550		
1961	10.8				237.452		
1962	18.9				216.452		
1963	17.3				142.927		
1964	25.9				122.474		
1965	29.8				76.864		
1966	27.3				75.207		
1967	15.9				99.258		
1968	25.7	1.000	1.000	1.000	74.745		
1969	28.4	0.782	0.681	0.745	49.687	48.578	
1970	23.6	0.477	0.427	0.367		30.349	
1971	24.9	0.438	0.369	0.303		35.365	
1972	33.3	0.379	0.337	0.246		28.315	
1973	28.2	0.347	0.287	0.254		16.744	
1974	19.8	0.390	0.315	0.300		16.697	
1975	17.7	0.422	0.345	0.301		10.761	7.417
1976	19.5	0.414	0.360	0.309			10.122
1977	21.7	0.431	0.341	0.332			9.516
1978	23.2	0.462	0.369	0.354			9.023
1979	22.6	0.481	0.322	0.378			6.451
1980	22.9	0.439	0.340	0.333			6.017
1981	24.1	0.347	0.282	0.234			9.193
1982	29.6	0.365	0.251	0.270			8.848
1983	15.1	0.367	0.281	0.273			6.400
1984	13.8	0.358	0.312	0.227			6.498
1985	29.7	0.395	0.283	0.291			9.480
1986	36.2	0.375	0.283	0.284			9.428
1987	39.8	0.330	0.240	0.249			6.098
1988	28.9	0.246	0.205	0.179			4.252
1989	26.7	0.212	0.193	0.149			5.465
1990	29.7	0.140	0.161	0.071			5.453
1991	25.6	0.141	0.145	0.081			5.618
1992	30.7	0.172	0.176	0.105			4.704

Source: Catches: 1957-1959 - ICCAT (1990); 1960-1961 - ICCAT (1991); 1962-1992 - ICCAT (1994)
 Taiwanese abundance indices - Punt *et al* (1996c)
 Japanese abundance indices - Uozomi (1996)

Table 2: Management variable estimates, their estimated CVs (expressed as percentages) and their 90% confidence intervals for the base-case analysis. Results are shown for the "standard" variance estimation procedure which makes no allowance for variability about the assumed age-specific selectivity function, and for an alternative procedure which does. Biomass and catch units are '000t.

Quantity	Estimate	No selectivity variance		With selectivity variance	
		CV	90% C.I.	CV	90% C.I.
<i>MSY</i>	25.2	7.9	22.4; 27.1	7.7	22.2; 27.1
<i>TAC_{sq}</i>	27.8	1.5	27.3; 28.3	7.5	25.5; 30.9
<i>RY (93)</i>	26.0	5.3	23.8; 27.1	5.2	23.8; 27.1
<i>B₁₉₉₂</i>	21.6	23.2	17.3; 30.0	23.1	17.4; 28.3
<i>B₁₉₉₂/K</i>	0.149	16.6	0.123; 0.188	16.1	0.124; 0.184
<i>B₁₉₉₂/B_{MSY}</i>	1.006	24.3	0.582; 1.120	24.3	0.569; 1.118
Steepness	0.878	15.1	0.679; 1.000	14.6	0.684; 1.000
<i>F₁₉₉₂/F_{MSY}</i>	1.188	33.9	1.025; 2.290	36.4	1.003; 2.417

Table 3: Management variable estimates and their CVs estimated by means of the "standard" procedure (and expressed as percentages), for the base-case analysis and the sensitivity tests. Biomass and catch units are '000t.

Quantity	Acronym			
	Base-case	With GLM 4	With GLM 7	M = 0.2yr ⁻¹
<i>MSY</i>	25.2 (7.9)	23.5 (12.7)	27.1 (8.8)	23.7 (8.2)
<i>TAC_{sq}</i>	27.8 (1.5)	28.3 (1.5)	28.4 (1.5)	26.9 (2.0)
<i>RY (93)</i>	26.0 (5.3)	25.0 (7.1)	27.0 (5.4)	24.4 (5.2)
<i>B₁₉₉₂</i>	21.6 (23.2)	34.5 (30.1)	26.5 (26.8)	26.0 (28.5)
<i>B₁₉₉₂/K</i>	0.149 (16.6)	0.210 (15.7)	0.184 (17.4)	0.149 (18.8)
<i>B₁₉₉₂/B_{MSY}</i>	1.006 (24.3)	0.825 (36.2)	1.266 (22.6)	0.617 (42.5)
Steepness	0.878 (15.1)	0.713 (23.6)	0.952 (15.3)	0.856 (18.1)
<i>F₁₉₉₂/F_{MSY}</i>	1.188 (33.9)	1.549 (42.0)	0.904 (55.8)	2.015 (36.3)

Quantity	Acronym			
	M = 0.4yr ⁻¹	GLM 1 only	GLM 4 only	GLM 7 only
<i>MSY</i>	25.9 (7.9)	21.9 (16.4)	17.9 (42.2)	21.2 (19.6)
<i>TAC_{sq}</i>	28.4 (1.6)	26.4 (2.8)	26.8 (2.8)	25.5 (2.7)
<i>RY (93)</i>	26.2 (6.0)	23.2 (10.2)	20.7 (14.6)	22.2 (10.2)
<i>B₁₉₉₂</i>	22.4 (20.0)	17.6 (44.2)	35.7 (66.3)	12.6 (54.1)
<i>B₁₉₉₂/K</i>	0.179 (14.0)	0.113 (22.1)	0.178 (27.0)	0.081 (24.7)
<i>B₁₉₉₂/B_{MSY}</i>	1.131 (16.9)	0.425 (32.7)	0.480 (22.5)	0.293 (42.0)
Steepness	0.812 (15.6)	0.693 (23.5)	0.446 (39.7)	0.669 (21.5)
<i>F₁₉₉₂/F_{MSY}</i>	1.042 (34.3)	3.014 (> 1000)	3.458 (> 1000)	4.254 (> 1000)

Quantity	Acronym			
	Ricker	GLM 1 only less 68/69	GLM 4 only less 68/69	GLM 7 only less 68/69
<i>MSY</i>	23.7 (3.6)	23.5 (6.5)	20.4 (8.7)	23.1 (5.9)
<i>TAC_{sq}</i>	27.3 (2.1)	27.1 (1.6)	27.7 (1.0)	26.5 (1.4)
<i>RY (93)</i>	23.7 (4.9)	24.7 (5.2)	22.7 (4.8)	24.3 (4.9)
<i>B₁₉₉₂</i>	19.8 (19.9)	18.2 (17.8)	38.2 (18.1)	12.9 (22.8)
<i>B₁₉₉₂/K</i>	0.166 (18.1)	0.123 (13.0)	0.206 (9.7)	0.089 (15.7)
<i>B₁₉₉₂/B_{MSY}</i>	0.465 (16.6)	0.581 (25.5)	0.620 (9.8)	0.426 (24.9)
Steepness	0.779 (8.3)	0.794 (13.4)	0.538 (16.4)	0.800 (11.9)
<i>F₁₉₉₂/F_{MSY}</i>	2.599 (15.3)	2.097 (28.8)	2.360 (17.3)	2.737 (19.4)

Table 4: The five alternative future *TAC* trajectories considered in this analysis. Units are '000t.

Year	Catch Trajectory				
	A	B	C	D	E
1993	28.6	28.6	28.6	28.6	28.6
1994	28.6	28.6	28.6	28.6	28.6
1995	28.6	28.6	28.6	28.6	20
1996	28.6	25	23	20	17
1997	28.6	25	23	20	17
1998	28.6	25	23	20	17
1999	28.6	25	23	20	17
2000	28.6	25	23	20	17
2001	28.6	25	23	20	17
2002	28.6	25	23	20	17

Table 5: The results of fully-deterministic projections [i.e. Risk Analysis method (a) - see text]. The definitions of the various performance indices are given in the text.

Performance Index	Catch Trajectory									
	A		B		C		D		E	
	1997	2002	1997	2002	1997	2002	1997	2002	1997	2002
Av Catch	28.6	27.7	27.2	26.1	26.8	25.4	26.0	24.0	25.6	22.8
$E(B_{fin}/B_{MSY})$	0.447	0.299	0.730	0.808	0.804	1.039	0.948	1.491	1.005	1.884
$P(B_{fin} > B_{MSY})$	0	0	0	0	0	1	0	1	1	1
$P(B_{fin} > B_{1992})$	0	0	0	0	0	1	0	1	0	1
$E(B_{fin}/K)$	0.066	0.044	0.108	0.120	0.119	0.154	0.141	0.221	0.149	0.279

Table 6: The results of the fully-stochastic projections [i.e. Risk Analysis method (d) - see text]. The definitions of the various performance indices are given in the text.

Performance Index	Catch Trajectory									
	A		B		C		D		E	
	1997	2002	1997	2002	1997	2002	1997	2002	1997	2002
Av Catch	28.3	26.7	27.1	25.5	26.7	25.0	25.9	23.8	25.5	22.7
$E(B_{fin}/B_{MSY})$	0.435	0.498	0.639	0.829	0.699	0.972	0.820	1.301	0.869	1.619
$P(B_{fin} > B_{MSY})$	0.016	0.144	0.118	0.328	0.190	0.403	0.388	0.566	0.454	0.673
$P(B_{fin} > B_{1992})$	0.000	0.160	0.082	0.359	0.209	0.444	0.416	0.621	0.496	0.762
$E(B_{fin}/K)$	0.073	0.081	0.107	0.134	0.117	0.157	0.138	0.211	0.146	0.265
$5\%(B_{fin}/K)$	0.037	0.021	0.040	0.022	0.045	0.023	0.066	0.026	0.075	0.036

Table 7: Performance indices for catch trajectory C for the four methods considered for calculating risk.

Performance Index	Risk Analysis Method							
	(a)		(b)		(c)		(d)	
	1997	2002	1997	2002	1997	2002	1997	2002
Av Catch	26.8	25.4	26.8	25.3	26.8	25.3	26.7	25.0
$E(B_{fin}/B_{MSY})$	0.804	1.039	0.804	1.042	0.793	1.066	0.699	0.972
$P(B_{fin} > B_{MSY})$	0.000	1.000	0.000	0.464	0.000	0.466	0.190	0.403
$P(B_{fin} > B_{1992})$	0.000	1.000	0.000	0.460	0.000	0.464	0.209	0.444
$E(B_{fin}/K)$	0.119	0.154	0.119	0.155	0.118	0.158	0.117	0.157
$5\%(B_{fin}/K)$	0.119	0.154	0.119	0.032	0.102	0.033	0.045	0.023

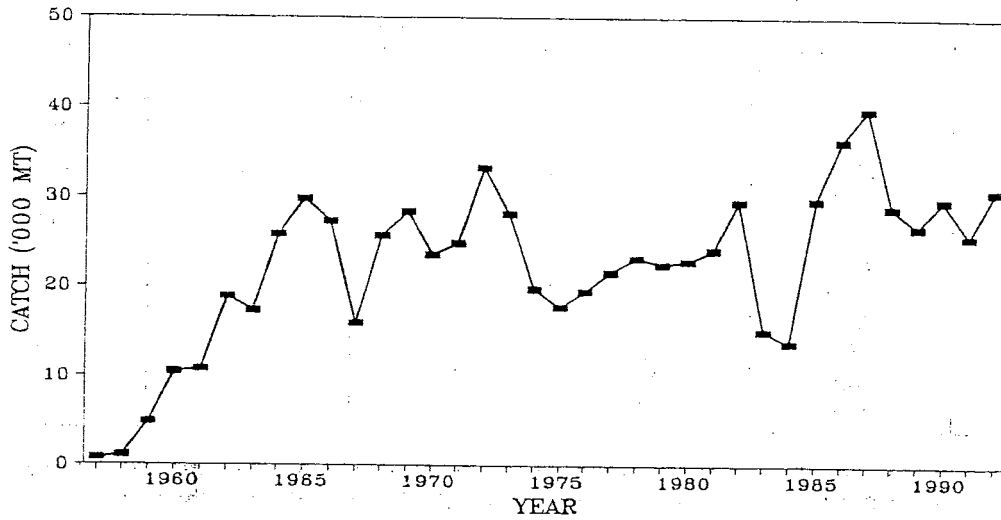


Fig. 1 Catch time series for the albacore population in the south Atlantic.

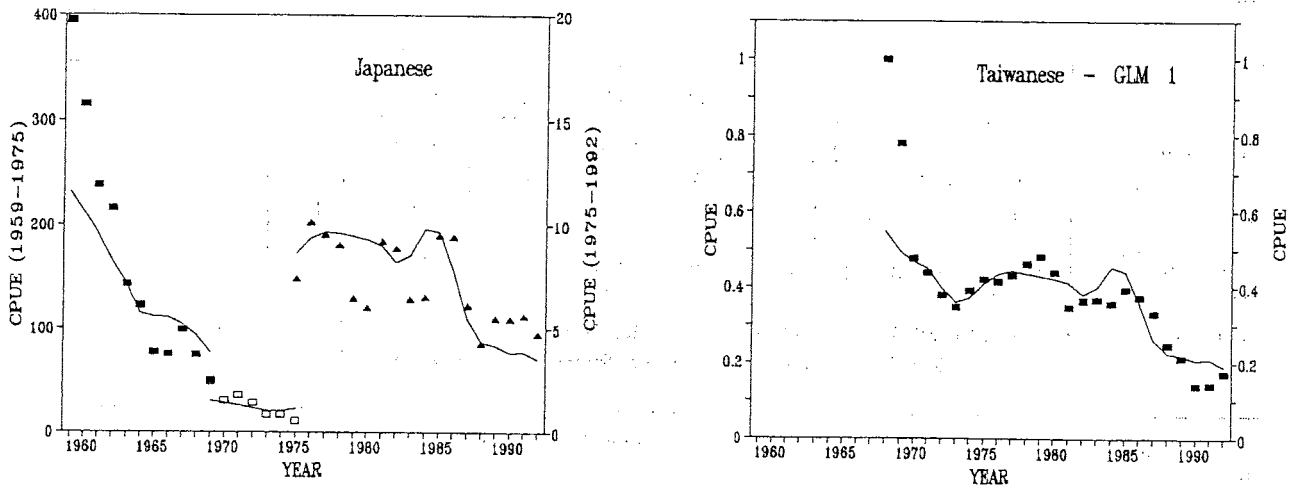


Fig. 2 Comparison of observed and model-predicted *CPUE* series. The predictions from the base-case assessment are shown by the continuous lines and the data by the symbols. In the left panel, the scale on the left vertical axis refers to the pre-1975 series, and that on the right to the post-1975 series.

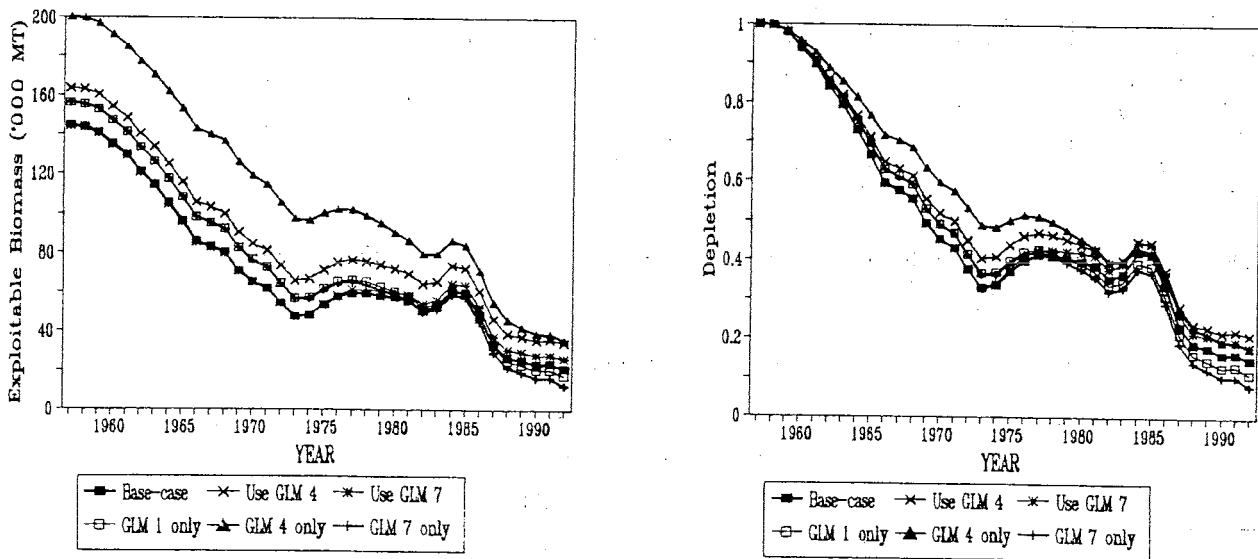


Fig. 3 Exploitable biomass trajectories for south Atlantic albacore obtained from the base-case application of the age-structured production-model, and from sensitivity tests which involve alternative choices of *CPUE* series for input. The left panel shows the exploitable biomass in absolute terms, while the right panel shows this as a fraction of its unexploited equilibrium level.

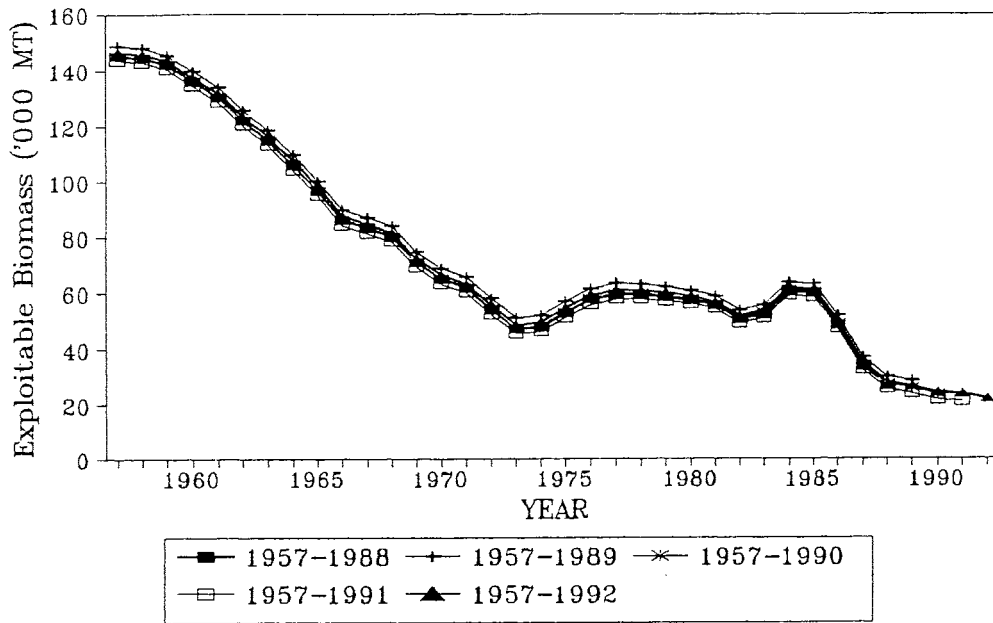


Fig. 4 Exploitable biomass trajectories for south Atlantic albacore obtained for the base-case set of specifications. Results are shown for five different choices for the most-recent-year of the assessment.

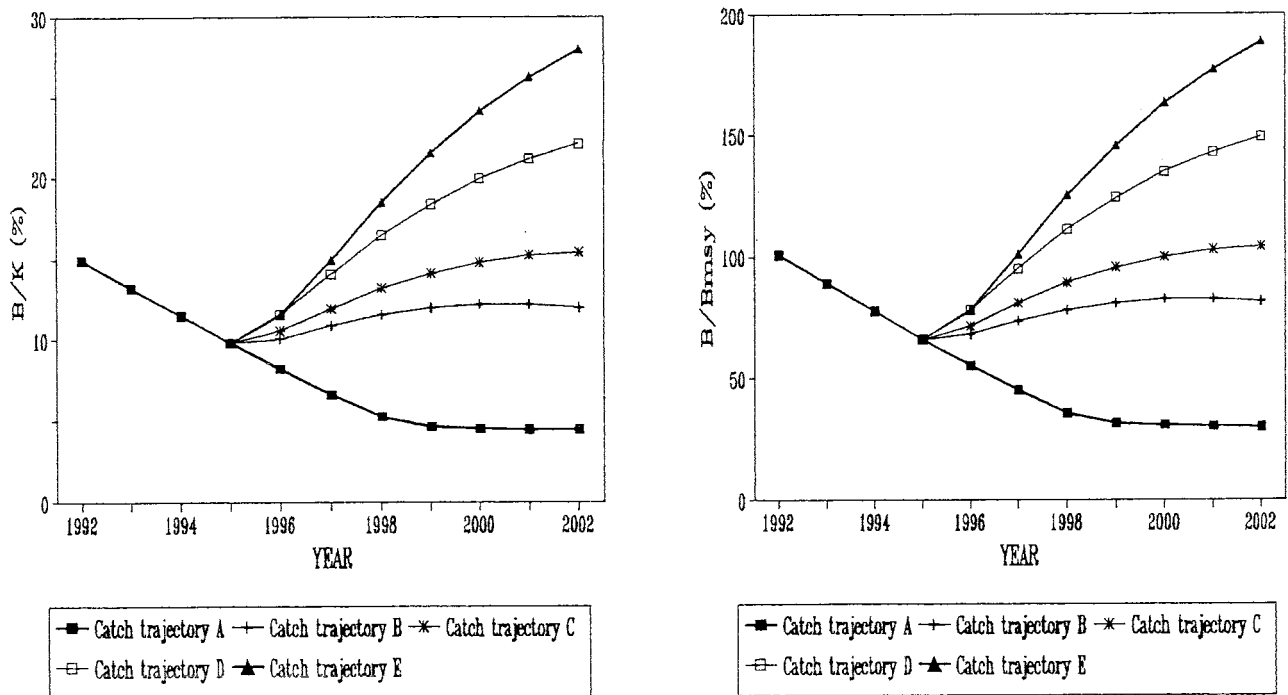


Fig. 5 Exploitable biomass projections for fully-deterministic calculations [Risk Analysis method (a)] for the base-case assessment and the various future catch trajectories of Table 4. Results are shown in terms of both B/K (left panel) and B/B_{MSY} (right panel).