2004 ICCAT BIGEYE TUNA YEAR PROGRAM SYMPOSIUM

(Madrid, Spain, 8-9 March 2004)
SUMMARY

The BETYP, a special program under the auspices of ICCAT, started its activities on 1 June 1999. It was a program specially requested by the members of the Standing Committee on Research and Statistics (SCRS) of ICCAT as a result of the important increase in catches of bigeye and the serious uncertainties about the state of the stock. Several field and research activities were carried out during the duration of the BETYP. This Symposium, the last scheduled activity of the BETYP, had the purpose of assembling and wrapping up all the information collected, and reaching conclusions that will assist in the assessment and management of this valuable resource.

KEYWORDS

Fishery statistics, Behavior, Stock assessment, Population structure, Tagging, Genetics, Otoliths

1 Introduction and objectives

The SCRS Chairman, Dr. Joao-Gil Pereira, opened the meeting of the ICCAT Bigeye Tuna Year Program (BETYP) Symposium.

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Several field and research activities were carried out during the duration of the BETYP. This Symposium, the last scheduled activity of the BETYP, had the purpose of assembling and wrapping up all the information collected, and reaching conclusions that will assist in the assessment and management of this valuable resource. Other presentations on the subject, covering worldwide activities regarding bigeye tuna, were presented during the Second World Meeting on Bigeye Tuna, which was held subsequently (see Collective Volume of Scientific Papers 57(2)).

The Agenda, List of Participants and List of Documents appear in Appendices 1 to 3.

The following persons served as discussion leaders (and rapporteurs):

- Statistics - P. Pallarés
- Biology - C. Hsu
- Behavior - N. Miyabe
- Stock structure - H. Arrizabalaga
- Stock assessment - V. Restrepo
- Field programs - G. Fisch
- General discussion and conclusions - J. Pereira

2 Statistics

As an introduction to this topic, the discussion leader gave a general presentation on the current state of Atlantic bigeye statistics, identifying the major problems and pointing out their possible effects, at the assessment level as well as the management level of this resource. The presentation is included in Appendix 4.
Overall, the level of the Atlantic bigeye statistics can be considered as good. In the ICCAT database there are historical catch series since the initiation of the baitboat and longline fisheries in the 1950s and 1960s, respectively, the average coverage rate of size sampling is between 60 and 70%, and there are effort data for the major fleets that catch bigeye tuna.

However, there are outstanding problems in relation to catches and size that were the subject of discussion. The problems related to effort, once identified, were considered to be part of the section on *Stock assessment* (section 6) and were not discussed under this item.

### 2.1 Catches

The discussion centered on the status of the IUU (illegal, unreported and unregulated) fleets. The catch by these fleets, estimated from the imports to the Japanese market, reached 20% of the total bigeye catches in the mid-1990s. Currently, it can be considered that these fleets have practically disappeared from the Atlantic as such and, in many cases, became part of the Contracting Party fleets, thanks to the series of measures adopted within the framework of ICCAT.

After recognizing the effectiveness of the measures adopted by ICCAT (development of positive and negative vessel lists, establishment of the Bigeye Tuna Statistical Document, etc.) to monitor these fleets, attention was drawn to some important points so that the problems associated to the fleets do not continue, specifically:

- The need for monitoring was considered so that the catches from these fleets all appear in the record and that the countries under whose flag they operate have effective control of the quality of these fleets. In this sense, the efforts made by Japan were recognized, done through agreements with the countries involved, for the improvement of their statistics.

- Attention was also called to the limitation of the statistical logbook, mandatory only for vessels over 24 m. It was noted that there is a longline fleet of vessels under this size with important bigeye tuna catches.

### 2.2 Size sampling

As regards the quality of the size sampling, the equatorial purse seine and baitboat fleets, based at Tema, and some longline fleets, were identified as those that are more problematic due to the low or nil sampling coverage.

The work carried out to improve the sampling system of the Ghanaian fleets within the BETYP was evaluated (SCRS/2004/035), and it was agreed that currently the major problem is at the level of the longline fleets.

The improvement of the statistics of these fleets, including size sampling and the collection of effort data, is essential since the assessments are based primarily on data from Japan (for sizes as well as for abundance indices) whose catches are becoming less important as compared to the catches of other longline fleets for which these basic data are lacking.

Given that during the last Commission meeting the Commission adopted a Resolution\(^1\) that creates a fund for the improvement of statistics of some of the members, the development of a protocol for the improvement of the statistics of these fleets was considered a priority. This protocol should identify the priority fleets, locate the most appropriate sampling sites, and define an adequate sampling scheme. Locating the sampling sites is a fundamental aspect for fleets that transship the majority of their catches.

There was also agreement that it was essential that the advisory work and the improvement of statistics include appropriate programs for the entry and validation of data and for the development of the statistics of specific countries.

Lastly, there was considerable interest in the creation of a statistical profile by country, and strong support for the recommendation to implement the form distributed by the Secretariat on the scheme for the collection and processing of basic data.

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\(^1\) Resolution by ICCAT on Improvements in Data Collection and Quality Assurance [Ref. 03-21].
3 Biology

Population parameters are of concern because they are particularly critical in studying stock dynamics and population management parameter estimation. In particular, age and growth, reproductive aspects including maturity ogive, and natural mortality are some of the important population parameters essential to the stock assessments. In this report, those parameters were reviewed for bigeye tuna in the three oceans, and possible conclusions were made for bigeye tuna in the Atlantic Ocean.

3.1 Age and growth

The growth of bigeye tuna varies according to the regions, since factors affecting growth, in terms of weight or size, are different by area.

Based on an analysis undertaken by the Secretariat of the Pacific Community (SPC) from tag recapture experiments for the western and central Pacific, a von Bertalanffy growth curve integrating measurement errors and individual variability in \( L_\infty \) was used on a data set of 254 reliable recaptures. The best fit between the length increment and the time at liberty was obtained through a segmented model, with linear growth for the data set with less than 500 days at liberty, and a von Bertalanffy model for time a liberty greater than 500 days (size range 40-110 cm FL). The annual \( K \) and \( L_\infty \) of this second segment are 0.4272 and 156.82 cm, respectively.

Modal progressions were used in the eastern Pacific (Tomlinson 1998). Two cohorts appear yearly in the fishery. The distribution between modes is reliable for fish smaller than 130-140 cm, but it becomes increasingly difficult beyond this size, where the individual variability generates a smoothing of the size distribution.

Since 1950s-1960s growth studies of Pacific bigeye tuna were based on increments between modal points of size composition (Iversen 1955; Shomura and Keala 1963; Yukinawa and Yabuta 1963; Kume and Joseph 1966; Suda and Kume 1967), on annuli counting of scales (Nose et al. 1967; Yukinawa and Yabuta 1963), and otolith increment counts (Hampton and Leroy 1998; Matsumoto 1998). Recently, a von Bertalanffy growth curve was modeled by reading annuli of the first dorsal spine, and found to be of no difference between males and females, then the growth equation was estimated as: \( L(t) = 208.7(1 - e^{-0.201(t+0.9906)}) \) with the length (fork length in cm)-weight (round weight in kg) relationship: \( BW = 3x10^{-5} FL^{1.0278} \) using FL ranges from 70 cm to 189.2 cm. (Sun et al. 2001). The comparison of von Bertalanffy growth curves estimated for bigeye tuna in the Pacific is summarized in Table 1.

Three techniques were used to age bigeye tuna in the Atlantic: hard parts, tagging and modal progression. As reported previously, age determination pursued for bigeye tuna from Atlantic Ocean was conducted by Gaikov et al. (SCRS/79/40); Draganik and Pelczarskj (SCRS/83/30); Delgado de Molina and Santana (SCRS/85/72); and Alves et al. (SCRS/1997/095). Results of growth studies on bigeye tuna in the eastern Atlantic Ocean indicate that there are discrepancies between growth parameters obtained from tag and recapture data and otolith annuli reading. Fagundes et al. (2001) reported that the growth parameters of bigeye tuna were \( K=0.136 \) and \( L_\infty = 295.5 \) cm from the Brazilian southeast-southern coast from 1977 to 1995 through the identification of the modal classes. A von Bertalanffy growth curve of bigeye tuna is formulated with \( K=0.180 \yr^{-1} \), \( L_\infty = 217.3 \) cm and \( t_0 = -0.613 \) year from 625 bigeye tagged and recaptured with a fork length (FL) range 39-124 cm sampling from the eastern Atlantic Ocean (SCRS/2004/039). Those von Bertalanffy growth curves estimated are tabulated (Table 2, see also SCRS/2004/059). Graphic comparison of the growth curves shown in Figure 1.

There have been no recent growth studies in the Indian Ocean. However, Tankevich (1982) provided a sex-specific growth curve of bigeye tuna from Indian Ocean. The von Bertalanffy growth equations are: females: \( L_t = 209.8\left[1 - e^{-0.193(t+0.86)}\right] \); and males: \( L_t = 423.0\left[1 - e^{-0.058(t+1.773)}\right] \), in which \( L_t \) is the fork length in cm. Besides those, the past analysis used modal progressions on juveniles (Mozambique Channel) and reading of hard parts for fish of a wider size range. The latter, which did not provided reliable results, produced estimates of 59 cm/year during the first year and 24 cm during the second year. Estimates on young fish (40-70 cm) were 16-18 cm/year.

3.2 Length-weight (LW) relationship

Five length-weight (LW) relationships, from the central Pacific (Nakamura and Uchiyama 1966), from the western Pacific Ocean (Morita 1973), from the Atlantic Ocean (SCRS/81/59), from the Indian Ocean (Cort
1986), and from the southwestern North Pacific Ocean (Sun et al. 2001; Wang et al. 2002), indicate that the LW relationships may show discrepancies among gear types, areas, seasons and between sexes.

The length (fork length, (FL) in cm)-weight (round weight, (BW) in kg) relationships of bigeye tuna caught around the waters off Chinese Taipei waters were not significantly different between males and females, and sexes-combined was formulated as: $BW = 5.856 \times 10^{-3} FL^{2.7884}$ (Wang et al. 2002). In the Atlantic Ocean, Park et al. (1981) formulated a LW of bigeye tuna as: $BW = 2.396 \times 10^{-5} FL^{2.9774}$. Moreover, the newly updated LW relationship by Song et al. (SCRS/2004/053) from the central Atlantic Ocean may be comparable. The sex specific relationship between round weight (kg) and fork length (FL in cm) are: Females: $W_f = 2.2590x10^{-4}FL^{1.9729}$; Males: $W_M = 2.8164x10^{-5}FL^{2.9275}$, and sexes combined: $W = 2.6472x10^{-5}FL^{2.9400}$.

### 3.3 Reproductive biology

There are no important new studies on this topic. Accordingly, the information regarding season, duration, batch size and frequency of spawning and the relationship between fecundity and size is still pending. However, Batalyants (SCRS/91/160) used the identification of hydrated oocytes, and sampled 3,000 bigeye tunas to study the spawning frequency of bigeye tuna, indicating that the bigeye tuna spawning frequency were 2.3, 3.1, 1.7, and 1.6 days during 1969-1970, 1975, 1979 and 1990, respectively.

### 3.4 Sex ratio

The observations available indicate that males are more numerous than females among the larger fish (>150 cm), except off southern Brazil. However, this sexual dimorphism is not as marked as in yellowfin or albacore, for which it occurs at earlier life stages.

An explanation of this phenomenon could partly involve sexual growth dimorphism (e.g., females growing more slowly) and/or differential M. It was pointed out that the variations on M and growth could be linked together, particularly at the level of the individuals: those which grow more rapidly will die sooner than those having a slower growth rate.

Extensive sampling could be carried out from longliners, when the fish are gutted, to provide more reliable estimates of the sex ratio by size. Pereira (SCRS/86/64) used 1,480 bigeye tuna sampled in the Azores from 1981 to 1986 to study sexual maturity and sex proportion, and found that a sex ratio of 0.9 showed that a slight predominance of females overall, but males outnumbered females in small size classes and above 160 cm.

Before that, Gaikov (SCRS/82/33) investigated seasonal dynamics of maturation, sex ratio of bigeye tuna in different areas of the Atlantic Ocean and correlation between their population in space and time for 1966-1979.

### 3.5 Maturity schedule

The age of maturity was 3-years-old in the previous assessment. There are no new studies on this topic.

### 3.6 Natural mortality

Natural mortality is critical to the estimation of management parameters (e.g., YPR). There is a reduction in the proportion of females in catches as size increases. Many researchers have observed that while the sex ratio of small tuna in catches is close to 50/50, males begin to dominate catches of large tuna (Kume and Joseph 1966; Hampton 2000; Hampton, Bigelow, Labelle 1998; Hampton, Lewis, Williams 1998; Miyabe SCRS/2002/152).

The change in sex ratio can be attributed to sex-specific natural mortality. Everett and Punsly (1994; in Harley and Maundrer 2003), although they analyzed sex ratio of yellowfin tuna, analyzed sex ratio in catches and speculated that there were three possible causes of the observed changes in sex ratios: (1) sex-specific growth, i.e., that females grow to a smaller maximum size than males; (2) sex-specific vulnerability, i.e., behavioral differences make large males more vulnerable to fishing gears than females; and (3) sex-specific mortality, i.e., females die out before they become large.

The spawning cost for female tuna is greater than that of male tuna, and this provides a mechanism for the increase in female mortality. Tropical tunas have the capacity to spawn all year round given suitable environmental conditions (Schaefer 1986). It should be noted that the decline in the proportion of females in catches occurs about 1.5 years after the age at 50% maturity (Kurt Schaefer, IATTC, Pers. Comm.).
The immediate natural mortality of bigeye tuna from BETYP tags has been estimated at about 31.1% and the extra continuous mortality rate (extra mortality due to carrying the BETYP-type tag) at 0.30/year (Gaertner and Hallier SCRS/2002/113). The instantaneous rate of natural mortality for juvenile bigeye tuna (average FL=56.6 cm) provided by this model (0.615/year for the mean and 0.675/year of the median) is consistent with previous estimates. In a Bayesian approach, a Sampling-Importance Resampling algorithm is used for updating Hampton’s estimate of M in light of information provided by the data. Based on the simulated posterior distribution, it appears likely that for juvenile bigeye, M is close to 0.62-0.67/year, with a confidence interval at 0.25-0.86/year (Gaertner and Hallier SCRS/2002/113).

The Richter and Efanov (1976) method was used for the calculation of natural mortality rate by Fagundes et al. (2001), the natural mortality rates was 0.53, 0.41 and 0.32 per year for the ages 3, 4, and 5, respectively. Fonteneau (SCRS/2004/061) reported this parameter might be a function of age.

3.7 Discussion and conclusion

Studies of population parameters are costly and difficult for bigeye tuna. Evaluating results of studies on ageing indicates that the growth curve obtained from the BETYP (SCRS/2004/039) is appropriate to represent the growth of bigeye tuna in the Atlantic, if all sampling data, i.e., otoliths sampled from Dakar and Abidjan are made available to use in estimating growth parameters. However, an alternate growth curve may be more appropriate to model growth of juvenile bigeye tuna instead of the traditional von Bertalanffy growth equation. In relation to the observed discrepancies of sex ratio and natural mortality between males and females, sex-specific growth curves should be studied to resolve those findings made by the assumption that growth of males is faster than females. Also the estimation method of growth parameters may lead to obtain different results and the method needs to be investigated to estimate them precisely.

Studies of reproductive biology are still very much needed. Sex ratios should be reexamined by size class. Maturity schedules, especially formulating a maturity ogive is required urgently for estimating stock-recruitment relationships and abundance accurately during assessment, even though it is timely and costly.

4 Behavior

The presentations given on this topic at the BETYP Symposium were mainly results from the initial attempts of pop-up tagging on adult fish. Two major problems were noted: early popping-off before the scheduled time and tag shedding due to inappropriate attachment (shape and material of darts, how to attach tag). Regarding the first problem, it was recommended that the scientists should work together with tag manufacturers to improve tag hardware (tag-releasing system, enhanced sensors, memories and geolocation algorithm). The second problem could also be resolved by exchanging information and techniques among scientists doing this tagging. If this activity was going to be pursued, the tags should be deployed where the major fisheries occur (i.e., eastern tropical Atlantic).

In the presentation on conventional tagging conducted in off Dakar and Canary Islands (SCRS/2004/032), the regular movements were reported, and it was thought that these locations were most suitable for archival tagging so that more concrete movements especially horizontal one could be effectively known.

During the BETYP, the dedicated conventional tagging cruises were conducted in the Gulf of Guinea. However, the releases were much fewer than expected. The reason for this seems to the lower availability of bigeye tuna for tagging. A number of points regarding possible reasons were discussed, but no conclusions were drawn. Further dedicated tagging is not warranted until this question is resolved.

5 Stock structure

5.1 Importance of stock boundaries

For effective fishery management it is absolutely essential that the stock structure assumed in the assessment and management process corresponds exactly to the true stock structure of the resource exploited. Not managing the fisheries in accordance with the stock structure of the species exploited can result in changes in their biological characteristics, productivity and genetic diversity (Ricker 1981). Further, it can lead to over-fishing and the collapse of the less productive stocks, hinder obtaining the maximum yield of the most productive stocks
Allendork et al. 1987), and can invalidate the effect of the recovery plans that are applied to highly exploited stocks (Ruzzante et al. 1999). In general, it can be said that the response of a stock to a specific management regime is unpredictable if the boundary of the management units does not correspond to the real stock boundary of the species.

Currently, many fisheries are regulated according to area schemes that do not necessarily correspond to the biological structure of the stocks (Pawson and Jennings 1996; Stephenson 1999; Ward, 2000). In these cases, the results of the stock assessment can be erroneous and it can be concluded that there is generally an important level of uncertainty in the assessments associated with the assumed stock structure (NRC 1994; Turner 1998)

Therefore, identifying stocks and determining the stock origin of the catches have become integral components of the assessment and modern management of the fisheries (Deriso and Quinn 1988; Shaklee et al. 1990; Carvalho and Hauser 1994; Begg et al. 1999; Waldman 1999).

5.2 Methodologies used

The use of fishery statistics, tag-recapture, meristics, body morphometrics, scales or otoliths, parasites as biological markers, immunogenetics, allozyme variation, genetic markers of mitochondrial DNA (mtDNA) or nuclear DNA (nDNA) and the elemental composition of the otoliths are among the methods most used to identify the stocks (Pawson and Jennings 1996; Begg et al. 1999).

However, each methodology has its advantages and disadvantages. For this reason, many authors suggest that the best focus for studies on stock limit is the multi-methodology type (Begg and Waldman 1999; Waldman 1999), especially for species that have important gene flow or complex structures (Ruzzante et al. 1999). The use is recommended of at least one genetic method together with a phenotypic method, tag-recapture and/or parasites (Begg and Waldman 1999).

The genetic differentiation among samples of marine fish is much less than among fresh water fish, for which determining the stock structure of marine fish can be particularly difficult (Ward et al. 1994; Hauser and Ward 1998; Waples 1998; Ward 2000). In the case of tunas and tuna-like species, as these are highly migratory species with pelagic larval phases, the problem increases since the migration of only few individuals per generation could provoke homogeneity of the genetic characteristics among the stocks (Ward 1995).

5.3 Studies carried out on bigeye tuna

In tunas, the stock structure assumed in the assessment and management framework is derived, above all, from knowledge of the large spawning areas, from fishery data and from tag-recapture information, not necessarily obtained from tagging programs with an adequate experimental design (Turner 1998). In recent years, however, and as new methodologies have advanced, the number of studies that provide information on biological tags (mainly of a genetic nature) has increased significantly.

In the specific case of bigeye tuna, the first immunogenetic study did not show any differences between the Pacific and Indian oceans (Suzuki 1962), and three decades later, a study with restriction enzymes in the cytchrome b, 12sRNA, and ATCO regions of the mtDNA did not show differences among 16 specimens from the Pacific (Chow and Inoue 1993).

Alvarado Bremer et al. (1998) analyzed 248 individuals from the three oceans with a combination of RFLP and sequences from the control region of the mtDNA. The results showed that the different haplotypes could be grouped principally in two clades. Clade I appeared in the Atlantic as well as in the Indian and Pacific oceans, and the Clade II was mainly in the Atlantic and only appeared in low frequency in the Indian and Pacific oceans. This study showed, for the first time, genetic differences between the Atlantic and Indo-Pacific oceans. However, the null hypothesis of homogeneity within the Atlantic Ocean or the Indo-Pacific Ocean could not be rejected.

In parallel, Grewe and Hampton (1998), in a study carried out with 9 samples from the Pacific (n = between 69 and 105) that were analyzed by RFLP from the ATCO and D-loop regions of the mtDNA and micro-satellites, the null hypothesis of a unique stock in the Pacific, which was, in principle, in agreement with results obtained by tag-recapture, could not be rejected.
The stock variation in the Indian Ocean was studied by Appleyard et al. (2002), who sampled in 5 locales and used RFLP from the ATCO fragment of the mtDNA with a restriction enzyme and analysis with 7 microsatellites, without finding sufficient evidence to be able to reject the null hypothesis of a unique stock of bigeye tuna in the Indian Ocean.

Chow et al. (2000) sampled 477 individuals from 15 samples from the three oceans, including 4 from the Atlantic and 7 from the Cape of Good Hope, and studied the genetic variability by RFLP from the ATCO and D-loop segments of the mtDNA. The ATCO was treated with a restriction enzyme that only gave two genotypes with large geographic differences in the genotype frequencies, such that it could be used as quasi diagnostic loci. The D-loop was treated with 2 restriction enzymes showing 15 different genotypes. The analysis of the geographic differentiation showed that the samples from the Atlantic and the Indo-Pacific were homogeneous within themselves and distinct between them, whereby they concluded that there was no genetic flow from the Atlantic Ocean to the Indian Ocean, and if there was genetic flow in the reverse direction, it would not be sufficiently important as to be able to change the genotype frequencies of the mtDNA of Atlantic bigeye tuna. The processing of the samples from the Cape of Good Hope with the quasi diagnostic enzyme showed the presence of individuals from the Atlantic and Indian Ocean stocks, for which there does not seem to be any physical barriers that hinder the mutual penetration of bigeye tuna from the Atlantic and Indo-Pacific stocks, although it seems that these return to the oceans of origin to reproduce.

It is considered that within the Atlantic spawning takes place mainly on both sides of the Equator in the respective summers of each hemisphere, but there is no evidence in the catch data and catch rates that supports the hypothesis of two distinct North-South stocks. Further, tagging studies indicate transatlantic migrations from the Gulf of Guinea to the central Atlantic to the North of Brazil, and from the Gulf of Guinea to the East Atlantic (Pereira SCRS/94/69). Thus, during the late 1970s and early 1980s the SCRS considered both alternatives: that of only one stock or two stocks (North and South), but since the mid-1980s, it has assumed the existence of a unique stock (Turner 1998).

5.4 BETYP contribution to knowledge on bigeye tuna stock structure

As concerns knowledge on stock structure, the BETYP centered on the tag-recapture and genetic analysis of mtDNA sequence. In the tag-recapture programs carried out within the BETYP, generally high recovery rates were obtained, but the majority of the recaptures were made relatively close to the tagging points, with few long-term recaptures (SCRS/2004/033; Hallier SCRS/2004/032). The fisheries involved in the Canary Islands and Dakar tagging are of a seasonal nature. Some of the long-term recaptures obtained were made in the same fisheries and areas close to the tagging areas in successive years, without being able to determine if the tuna had been in said area during the entire period at large, or if they had emigrated or immigrated during this period. Therefore, in the discussion it was recommended that archival tags be used in order to be able to discern if the bigeye tuna are residents in those areas or not.

Due to the low number of recaptures in areas distant from the tagging areas, the results that were obtained by tag-recapture were not very informative for a general view of bigeye tuna distribution in the Atlantic and the relationship between distant areas in that ocean. At any rate, an historical review was made of all the tag-recapture experiments carried out on Atlantic bigeye (SCRS/2004/032), and the results showed at least some migration connecting the Gulf of Guinea with the area of Senegal, Canary Islands, Azores Islands and waters close to Cuba. Although the information is not the best, the analysis of all the available information from conventional tag-recapture up to the present time is in agreement with the null hypothesis of a unique stock in the Atlantic.

Among the causes that could cause the lack of long-term recaptures, the large percentage of recaptures obtained in the short-term was noted (in part due to the tagged fish in the “manchas” fisheries of the Canary Islands and Dakar remaining associated to the vessels following release) as well as the problem of the lack of recaptures from the longline fleet. In this sense, it would be convenient to carry out tag seeding trips to estimate reporting rates of tags of the different fleets, but although these experiments could be carried out on some fleets, such as purse seine, it would be difficult to carry them out in the longline fishery since the fish are processed on board one by one. The presence of on-board observers was suggested, which could increase the recapture rates by these fleets, as occurs in other species.

As concerns the genetic analyses (SCRS/2004/040), sequences were made on 407 bp from the control region of 295 bigeye tunas from 4 Atlantic regions (Côte d’Ivoire, Canada, Canary Islands, Azores Islands) and one Indian Ocean region. The samples from the Canary Islands and the Gulf of Guinea were sampled in 2001 as well as in
2003 to study the stability over time of the results. These confirmed the presence of two distinct clades in the Atlantic, one specifically from the Atlantic and another that also inhabits the Indian Ocean (Alvarado Bremer et al. 1998). Notwithstanding, no geographic variations were observed in the proportions of both clades in the different samples, not even among the samples obtained in Canary Islands and the Gulf of Guinea in different years. In principle, these results concur with the hypothesis of a unique stock in the Atlantic, currently used by the SCRS, and therefore allows more confidence in the assessment analyses carried out up to now, as concerns uncertainty associated with the assumed stock structure.

At any rate, and taking into account that the mtDNA only reflects the maternal lineage, it was also agreed to analyze nuclear DNA of bigneye tuna as soon as possible to confirm that there are not two distinct stocks living in the same area (SCRS/2004/030). Further, it was considered interesting to use small samples in the analyses to reduce the probability of mixing among samples. The use of alternative methods to differentiate the stocks, such as morphometrics, was also recommended, but these studies were considered of lesser priority than the study of nuclear DNA.

In spite of the fact that accumulated knowledge up to now does not warrant rejecting the null hypothesis of a unique Atlantic stock, it was recognized that this stock could show certain characteristics of viscosity, in the sense that the migrations of the individuals could be moderate and not very fluid among distant regions. Given the potential application of this type of information in integrated assessment models of the MULTIFAN-CL or FASST type, it would be convenient to expand knowledge on the migrations between the different regions of the Atlantic Ocean.

6 Stock assessment

6.1 Background

The ICCAT Standing Committee on Research and Statistics (SCRS) is responsible for assessing the status of stocks that are managed by ICCAT. Typically, assessments are conducted every 2 to 3 years. The assessments are made by a working group that is made up of scientists from the contracting and collaborating parties ("national scientists"), with logistical support from the Secretariat. In conducting assessments, the working groups use the data maintained by the Secretariat (primarily catches and size samples), and data tabulated by the national scientists (primarily CPUE data and other auxiliary information), and a variety of methods. This report summarizes some of the different inputs/choices of the Atlantic bigneye stock assessments, with special emphasis given to uncertainties. As well, the report summarizes the main points discussed during the BETYP Symposium.

6.2 Assessment components

6.2.1 Total catch (Task I)

The main gear types that fish for Atlantic bigneye are purse seine, baitboat and longline. In terms of weight, purse seine and baitboat landings account for about 16% and 18% of the total, while longline accounts for about 65% of the total. Therefore, in a relative sense, uncertainties in longline landings are more likely to dominate the assessment if it is based on biomass (e.g., a production model). On the other hand, if the assessment is based on numbers (e.g., a VPA), then the purse seine and baitboat catch data will become more important because these gears catch more young fish.

- For longline, it is thought that a major source of uncertainty has been unreported catches. The relative importance of this problem is thought to be decreasing.
- For baitboat and purse seiners, species composition is thought to be a main source of uncertainty. Changes in targeting and fishing operations (e.g., FADs) are thought to exacerbate this problem.

6.2.2 Catch at size/age

6.2.2.1 Sampling

One of the components of Task II data is information on the size composition of catches by fishery. These data are used by the assessment working groups to infer the overall size structure (or age structure) of the catches. For bigneye tuna in the ICCAT database, the ratio of Task II catch data with size sample information, to Task I catches is about 59%. This means that roughly 60% of the total landings can be associated with some type of
measurement. However, this statistic is an overestimate of the actual level of size sampling because some countries report “catch-at-size” data, i.e. size samples already raised to match some higher level of aggregation (for example, to match the official Task I data).

In past ICCAT assessments of BET, the working group has made substitutions in order to fill in the gaps in the size data and obtain a total estimate of catch-at-size. In the process of making substitutions, it is assumed that the size structure of the catches of a given fishery at a given time is identical to the structure of another fishery at the same time (or identical to the structure of the same fishery at another time, and so on). At the 2002 assessment, 34% of the landings in recent years needed substitutions because they were not associated with size data.

6.2.2.2 Growth

Some of the methods used by ICCAT in the past use as an input an estimate of the total catch matrix, by age and year. This matrix is obtained by applying cohort slicing to the total catch-at-size matrix, using a constant growth equation (from Cayré and Diouf SCRS/83/80). Doubts have been raised recently about the way in which the age-slicing algorithm has been applied recently, and this will be discussed in one of the presentations made during the Second World Bigeye Meeting (SCRS/2004/059). More generally, other ICCAT working groups have also expressed doubts in the past about the appropriateness of applying slicing which ignores variability in length at age.

One of the primary objectives of the BETYP has been to improve knowledge of bigeye growth, from otoliths and tagging (see Section 3, Biology). As a result of these studies, it is likely that the growth curve used by the group will be revised. In addition, some of the integrated statistical models being used (e.g. MULTIFAN-CL) offer the capability of directly estimating growth parameters in the assessment.

6.2.3 Abundance indices

The Atlantic bigeye tuna stock assessments use indices of abundance that are based on CPUE data. There are several sources of uncertainty related to these indices.

For longlines, effort is measured in numbers of hooks. The indices are typically calculated using some process of standardization (e.g., via generalized linear models, GLMs) in order to factor out changes in CPUE that are thought to be unrelated to abundance. Nevertheless, it is not always possible to model these extrinsic factors, especially when relevant data are not available. At the last assessment, the working group did not use a longline index because it felt that the trend in standardized CPUE contained strong effects due to changes in species targeting over time.

For baitboat and purse seine fisheries, it is considerably more difficult to obtain a quantitative measure of effective fishing effort. Many of the trends observed in the available CPUE indices are thought to be related to changes in efficiency that cannot be easily factored out by use of traditional standardization techniques. As a result, the working group has decided that the available CPUE series for these fisheries do not represent abundance.

Therefore, the working groups have ended up using only longline indices to model trends in abundance. This is problematic because longline fisheries tend to catch older fish, and thus there are no reliable ways to model trends in small fish abundance. This is one very important source of uncertainty in the assessments because the estimated trends in recruitment tend to be driven by model assumptions rather than by data.

6.2.4 Natural mortality

The assessment working group uses a vector of 0.8 yr\(^{-1}\) for ages 0 and 1, and 0.4 yr\(^{-1}\) for older ages. Projects related to the BETYP (SCRS/2002/113) have estimated natural mortality from tagging data which gave results that are consistent with the estimates used by the group. Such studies are likely to result in refinements to the vector of natural mortality that is used by the assessment working group.

6.2.5 Sex ratio

Some studies have shown that the sex ratio can differ substantially from 1:1, depending on fishery, area and season. However, no attempts have been made to produce sex-specific assessments for Atlantic bigeye tuna. This
practice is likely to continue to be the case due to lack of sex-ratio data, but the working group do not seem to view this as a major source of uncertainty.

6.2.6 Spatial structure

One of the main objectives of the BETYP has been to examine the stock structure of Atlantic bigeye tuna. The working group assumes a single, Atlantic-wide stock, and so far the evidence collected seems to be consistent with this assumption.

Nevertheless, even if there is a single stock, it may be useful to apply spatially-explicit models that can take into account processes such as fish movement and the regional nature of fleet-specific CPUE indices. So far, the assessment working group has not used spatially-explicit models, although attempts are being made with the integrated statistical models.

6.2.7 Choice of assessment models

The types of models used traditionally by the working group can be classified in many ways. Here they are classified, somewhat arbitrarily, in order of increasing complexity:

6.2.7.1 Biomass production models

These models make use of a series of total landings and a single index of abundance. Many simplifying assumptions (both implicit and explicit) are made in order to use these models. Some of the main drawbacks from using them are that all age-structured time lags are ignored, and that a constant selectivity is assumed implicitly. These are problematic in the case of bigeye where surface fisheries target younger fish and longline fisheries take older fish sequentially. On the other hand, simple models can be used for simple types of management advice, and working groups have plenty of time to examine the sensitivity of the results to various assumptions and data choices.

In the last assessment, the group used ASPIC (Prager, 2002) with a Fox-type production model form as the main basis for management advice.

6.2.7.2 Age-structured production models

These models are intermediate in terms of complexity. They assume some explicit relationship between stock and recruitment and thus incorporate age-specific time lags. Some of them allow for random deviations from the deterministic stock-recruitment relationship.

The simplest models in this class make a simple assumption about selectivity and follow a single fishery. One such example is the simplest form of Delay-difference model. Other applications (e.g., ELBUEY) account for changes in selectivity over time or between fleets.

One of the main sources of uncertainty in the Atlantic bigeye applications of age-structured production models is that the fleet-specific selectivities have been input (as opposed to estimated by the model). This is problematic because the analyses are fragmented thus making the group more vulnerable to mistakes in data handling, etc. It can also lead to inconsistencies in the way data are treated in the different modeling stages.

6.2.7.3 VPAs

These models allow for more complexity in terms of modeling fisheries separately and not necessarily making assumptions about the form of the stock-recruitment relationship.

VPAs rely on the assumption that the catch-at-age matrix is known without error. This is a major source of uncertainty for Atlantic bigeye, where serious doubts have been raised about the cohort-slicing process for converting catch-at-size into catch-at-age. Another (related) problem is that the back-calculated results can be quite sensitive to the way in which the plus group, the oldest age in the catch, is modeled.

In addition, VPA applications for Atlantic bigeye have tended to fail for a reason more related to data than to the type of model: the lack of reliable indices of abundance for young fish. Thus, the estimated trends in adult
biomass largely follow the trend in whatever longline CPUE index is used, while the trend in recruitment can be quite variable depending on modeling assumptions.

In recent years, the BETYP has been focusing on implementing integrated statistical models, which are briefly introduced below.

6.2.7.4 Integrated statistical models

Integrated statistical models (e.g., MULTIFAN-CL and FASST) are viewed as necessary in order to overcome many of the problems mentioned for the other models.

One of the main features of this type of models is that they use the data pretty much as they exist in the database. For example, instead of undertaking the process of (Raising-->Substitutions-->Slicing-->Catch-at-age), the models use catch by fishery and size samples. Where the size samples are sparse, the model estimates will be less precise.

Fisheries can be defined in a flexible way, as flexible as the data allow. In general, spatial structure can be defined to be realistic in terms of accommodating fisheries that occur in different geographical regions, and also to add biological complexity such as migratory patterns.

The models can also be implemented to use auxiliary data, such as tagging, which can be useful for estimating movement or growth parameters.

In theory, integrated statistical models can be formulated to estimate many (most) parameters in the system: selectivities, growth, natural and fishing mortalities, movement, catchability changes through time, the stock-recruitment relationship, etc. In practice, the available data may not allow something very ambitious, so the most likely use for these models in the near future is to circumvent some of the more obvious problems encountered with the other types of assessment models.

6.2.8 Projections

Projections can be made with each of the types of models mentioned above. In some cases, the projections are done separately from the assessment of current stock status, which can lead to inconsistencies.

Projections made with production models tend to reach new equilibrium levels too rapidly, perhaps as a result of their failing to account effectively for age-specific lags.

In general, one of the most uncertain aspects of projections is the selectivity level to be assumed into the future. Most assessments assume that the most recent selectivity pattern (e.g., the average selection pattern for the last 3 years) will be continued into the future, something that may not be particularly realistic in cases where the various fisheries target either smaller or larger fish. The Commission is interested in alternatives to the current minimum size regulation for bigeye (3.2 Kg), a question that can be viewed as a type of (equilibrium) projection analysis.

6.2.9 Quality control

ICCAT bigeye stock assessment working groups use various types of diagnostics during the meetings. These may include:

- Descriptive analyses and statistics of the catches by fishery.
- Standard GLM diagnostics (residuals, qq plots, etc.) for GLM fits to CPUE data
- Bubble plots of catch-at-age by year
- Plots of residuals of the fitted CPUEs in the assessment
- Log-likelihood or AIC for different model formulations
- Plots of recruitment and SSB trends

However, diagnostics are seldom utilized in a systematic way, nor are they applied consistently from one assessment to the next. Therefore, the level of scrutiny that the assessment results receive may vary over time. The SCRS has attempted to introduce some quality control procedures such as the ICCAT software catalog, and fuller documentation and storage of all the assessment inputs and outputs. While the quality control process has improved substantially in recent years, there is room for much more improvement. The bigeye working group
may benefit from developing a set of quality control procedures and diagnostics that can be applied in a working

group environment and that are specifically tailored to bigeye.

6.3 Discussion

With regards to projections, participants noted that recent applications were ad-hoc and that it may be useful to

standardize some of the procedures used, e.g., to assume future selectivity patterns.

With regards to CPUE standardization, participants reiterated concern with the lack of reliable indices for young

fish. More efforts should be devoted to investigate the factors that affect catchability in purse seine fisheries, and
to collect the appropriate data to account for these factors.

With regards to more complex models, it was agreed that integrated statistical models could overcome many of
the problems mentioned above. However, participants also suggested that the adoption of integrated statistical
models for routine assessments should proceed cautiously. In this respect, the following pros and cons were
offered:

PROS:
– More flexible models allow for more realism. Biases could be reduced.
– These models allow for more realistic/rigorous estimates of uncertainty.
– Multiple types of data can be used together in the same model.
– The models can make use of the data at the same level as they are reported without the need for the
  machinery comprised of substitutions, age-slicing, etc.

CONS:
– More sophisticated models do not necessarily lead to better management advice.
– More sophisticated models require increase workload by national scientists and Secretariat staff.
– Routine use of these models requires changes in the way ICCAT assessments are conducted. More inter-
  sessional work will be required to maintain and update datasets.

Participants also noted that some of the problems associated with over-parameterization of these models could be
avoided through careful consideration of the environmental processes that affect the populations. For example, if
catchabilities or recruitment could be linked to environmental variables, then the models could incorporate
relevant environmental indices, thus increasing the degrees of freedom.

7 Field programs

The field program of the BETYP is summarized in SCRS/2004/030. The following were related comments
raised during the discussion:

Purchasing the bait from local fishermen improved relations between fishermen and the program.

The boat and crew that were chartered in Azores were satisfactory. However, some difficulties with the crew
were encountered during cruises in the Gulf of Guinea. This was attributed to working in an unfamiliar
environment.

Large tagging operations cannot be done from a type of vessel other than a baitboat. And the baitboat chartered
for BETYP was suitable for the purpose of the program.

BETYP faced, as do all tuna tagging or fishing operations, some difficulties with the natural availability of bait
and tunas. Overall, bigeye were difficult to find and to catch (the availability of bigeye was over-estimated).

The presence of the coordinator on board or a chief scientist of sufficient competence and responsibility is
necessary not only to implement the tagging strategy, but also to solve many of the technical problems, as well
as to maintain good relations with the local authorities and the local fishermen.

The different types of tagging strategies (chartering Ghanaian and Portuguese baitboats under two different
terms, opportunistic tagging on board Ghana baitboat) implemented by BETYP prove again that the tagging
strategy should be properly adapted to what objectives are being sought. Opportunistic tagging is difficult to set-
up and should be limited to simple objectives such as data on tuna movements. In the terms of the charter agreement for the boat, it should be clear for all participants (boat owner, captain, crew, scientific team) that the only task of the vessel is to tag fish and in no way to profit from money with the fish caught and not tagged.

This implies the need for some sort of incentive for the crew that boosts their interest in the success of tagging. However, it should always remain the responsibility of the scientific leader to decide what fish are tagged.

8 General discussion and conclusions

At the end of the BETYP Symposium, the participants considered that this special ICCAT research program has answered some of the questions that were posed by the program, but also that more research was necessary on Atlantic bigeye tuna. It was also noted that in some areas the research was not yet completed.

The details of the discussions held are given under the different agenda items.

It was considered that the research developed during the BETYP on various subjects like biology, behavior, movement patterns and fisheries, had given very positive results, but they are still insufficient to answer the major questions concerning bigeye that were made at the beginning of this research program.

One important pending question at the end of the BETYP is the real level of natural mortality of bigeye as a function of the age, which remains a limiting factor in stock assessment and in the evaluation of the real impact of the very high level of juvenile catches. Uncertainty also remains on the effects of FAD fisheries on bigeye stocks and the possible influence on changing the behavior of the species.

The difficulties encountered during the tagging activities of small bigeye have also been discussed, and some participants emphasized the fact that small bigeye were more difficult to find and to catch than it was initially estimated, hence the availability of young bigeye to the surface gears was overestimated. In spite of that, the global picture of the tag-recovery program was consistent with results of genetic studies and with the stock structure assumed at present. The ongoing research on nuclear DNA would definitely confirm that.

On electronic tagging, although successful applications of internal archival tags have been observed for bigeye (SCRS/2004/057), the general impression was that pop-up tag technology did not work as well as for other species, which may be due to more pronounced vertical migration behavior of bigeye. In spite of this, the bigeye tagged in Azores during their trophic migration (SCRS/2004/034) showed more surface behavior in comparison to what is observed in tropical areas of the Pacific.

The participants considered as a highly positive result of the BETYP the new integrated models that are under development, such as FASST exploratory model, and the first use of the MULTIFAN-CL on Atlantic bigeye. It is expected that those models will provide a more comprehensive assessment of the bigeye Atlantic stock.

9 Closing Comments from the Chairman

Dr. Pereira announced to participants that the BETYP Symposium would be the last scientific meeting attended by Dr. Adolfo Ribeiro Lima as Executive Secretary of ICCAT, due to his imminent retirement from the ICCAT Secretariat. On behalf of the ICCAT scientific community, he thanked Dr. Lima for his constant and strong support of science within the Commission. He also noted that Dr. Lima had been one of the most influential proponents of the BETYP. Participants joined in thanking Dr. Lima and wishing him well in the future.

Dr. Pereira thanked Guillermo Fisch for his work as Coordinator of the BETYP and the rest of the Secretariat for their involvement in various BETYP tasks.

Dr. Pereira finally noted that the BETYP would have not been possible without contributions outside the regular ICCAT budget. He explained that the main contributions to the Program had been made by Japan and the European Community, and thanked them as well as the other contributors for their support of this important research project.

Finally, Dr. Pereira thanked those scientists that presented papers at the Symposium, the discussion leaders and rapporteurs, and all participants in general.
It was agreed that the report of the BETYP Symposium would be adopted by mail. The Symposium was adjourned on 9 March 2004.

References


## Table 1. Estimates of von Bertalanffy growth parameters for bigeye tuna from Pacific Ocean.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Regions</th>
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<th>Size range (cm)</th>
<th>Investigators</th>
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## Table 2. Estimates of von Bertalanffy growth parameters for bigeye tuna from Atlantic Ocean., in which length is measured as fork length in cm.

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