CHAPTER 2.1.2: BIGEYE TUNA	AUTHOR: IEO	LAST UPDATE: Nov. 30, 2006

2.1.2 Description of Bigeye Tuna (BET)

1. Names

1.a Classification and taxonomy

Name of species: *Thunnus obesus* (Lowe 1839)
Synonyms: *Germo obesus* (Lowe 1839)
Neothunnus obesus (Lowe 1839)
Parathunnus obesus (Lowe 1839)
ICCAT species code: BET
ICCAT Names: Bigeye tuna (English), Thon obèse (French), Patudo (Spanish)

According to Collette & Nauen (1983), Bigeye tuna is classified in the following way:

- Phylum: Chordata
- Subphylum: Vertebrata
- Superclass: Gnathostomata
- Class: Osteichthyes
- Subclass: Actinopterygii
- Order: Perciformes
- Suborder: Scombroidei
- Family: Scombridae
- Tribe: Thunnini

1.b Common names

List of vernacular names used according to the ICCAT (Anon. 1990), *Fishbase* (Froese & Pauly Eds. 2006) and the FAO (*Food and Agriculture Organization*) (Carpenter Ed. 2002). Names asterisked (*) are standard national names supplied by the ICCAT. The list is not exhaustive, and some local names may not be included.

American Samoa: To'uo
Angola: Atum-patudo, Patudo
Argentina: Ojos grandes, Patudo
Australia: Bigeye
Barbados: Albacore
Benin: Gégú*, Guégou
Brazil: Albacora, Albacora bandolim*, Albacora-cachorra, Albacora-olhão, Albacora-olho-grande, Atum, Atum-cachorra, Atum-cachorro, Bonito-cachorro, Patudo
Canada: Bigeye, Bigeye tuna*, Thon ventru*
Cape Verde: Albacora, Atum, Atum-de-olhos-grandes, Atum obeso, Atum-patudo, Cala*, Chafarote, Chefarote (peces pequeños), Patudo
Chile: Atún de ojo grande, Atún ojos grandes
China (People's Rep.): 大眼副金槍魚 (Da yan fu jin ciang yu), 大眼金槍魚 (Da yan jin ciang yu)
Chinese Taipei: 短鮪 (Duan wei), Tha mu we*, Tha yen we
Colombia: Atún, Atún ojo gordo, Ojo gordo
Côte d'Ivoire: Patudo
Cuba: Atún ojo grande, Ojigrande
Denmark: Storøjet tun
Djibouti: Bigeye tuna, Thon obèse

Dominican Rep.: Albacora
Ecuador: Albacora, Atún ojo grande
Finland: Isosilmätonnikala
France (Martinique): Gro ton, Patudo, Thon obèse
France: Patudo, Thon aux grands yeux, Thon obèse*, Thon ventru
Francia (Tahiti): A'ahi o'opa, A'ahi tatumu
Germany: Großaugen-Thun, Großaugen-Thunfisch, Großaugenthun, Thunfisch*
Granada: Guégou
India: വലിയ ചൂര (Valiya-choora), Bigeye-tuna
Italy: Tonno obeso
Japan: Bachi, Darumeji, Mebachi*, Mebuto, Young- (Daruma)
Kiribati: Te takua
Korea: Nun-da-raeng-i*
Malaysia: Aya hitam, Bakulan, Tongkol
Marshall Islands: Bwebwe
Mauritania: Big eye, Patudo, Thon obese
Mauritius Islands: Big eye, Thon aux gros yeux, Thon gros yeux, Thon obèse
Mexico: Atún ojo grande, Patudo
Micronesia: Bigeyed tuna, Taguw, Taguw peras, Taguw tangir
Morocco: Gros yeux, Patudo*, Thon obèse
Mozambique: Patudo
Namibia: Dickleibiger Thun, Grootoog-tuna, Großaugiger Thun, Thun, Tuna
Netherlands (Antilles – Papiamento): Buni fluitdo, Buni wowo di baka
Netherlands (Holland): Grootoogtonijn, Storje
New Zeland (Tokelau): Kahikahi, Kakahi, Lalavalu
New Zeland: Bigeye tuna
Nicaragua: Patudo
Norway: StØrje, StorØyet
Oman: Jaydher
Palau (Trust territories of the Pacific Islands): Aáhi o'opa, Aáhi tatumu
Papua N. Guinea: Big eye tuna, Big-eye tuna, Matana bwabwatana
Peru: Atún ojo grande, Patudo
Philippines: Bangkulis, Bantala-an, Baragsikol, Bariles, Barilis, Bigeye tuna, Bronsehan, Bugok, Buldog, Bulis, Karaw, Kilyaong, Panit, Panit pakulan, Sobad, Tambakol, Tambakul, Tuna, Tulingan
Poland: Opastun
Portugal (Azores): Albacora, Alvacor, Alvacora, Atum, Bigeye tuna, Big-eye tunny, Patudo*
Portugal (Madeira).: Atum patudo
Portugal: Albacora-ôlho-grande, Atum patudo, Atum-patudo
Romania: Ton bondoc, Ton obez
Russian Fed.: тунец большеглазый (Bigeye tuna)
Salomon Islands: Atu igu mera, Bigeye tuna
Samoa: Asiasi, Ta'uo
Sao Tome and Principe: Atum fogo
Senegal: Thon obèse
Seychelles: Big eye tunny, Thon gros yeux
Sierra Leona: Bigeye tuna
Somalia: Yajdar-baal-cagaar
South Africa: Bigeye tuna, Bigeye tunny*, Grootoog-tuna (Afrikaans)
Spain (Canary Islands): Tuna
Spain: Atún, Bonita, Monja, Ojo grande, Ojón, Patudo*, Zapatero
Sweden: Storögd tonfisk
Tanzania: Jodari
Turkey: Irigözorkinoz baligi, Irigözton baligi, Kocagoz orkinos
United Kingdom (Saint Helena): Coffrey
United Kingdom: Bigeye tuna, Bigeye tunny
United States (Hawaii): Ahí, Ahi po'onui, Bigeye tuna fish
United States: Bigeye, Bigeye tuna*
Venezuela: Atún ojo gordo, Ojo gordo *, Ojona
Vietnam: Bigeye tuna, Cá Ngừ mắt to

2. Identification

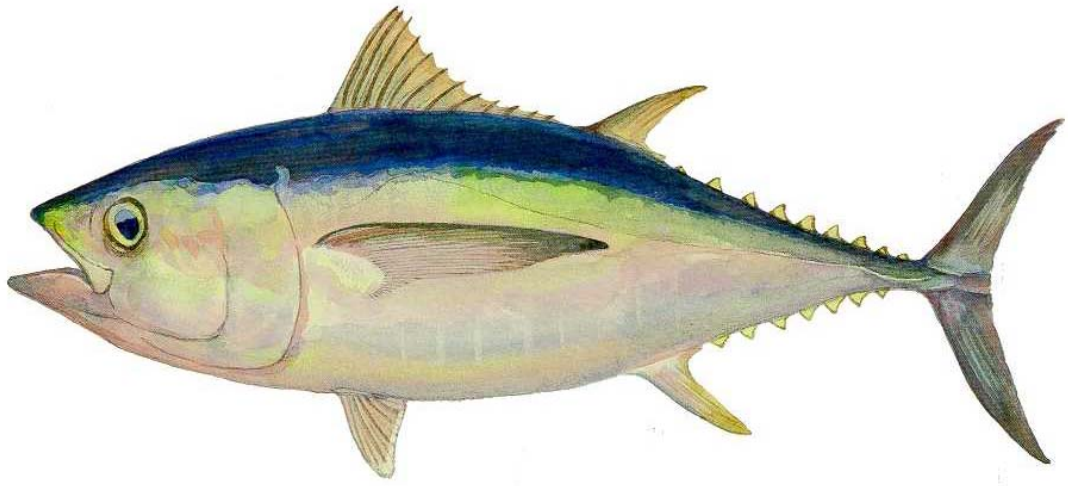

Figure 1. Drawing of an adult Bigeye tuna, courtesy of the IATTC (Inter-American Tropical Tuna Commission).

***Characteristics of* Thunnus obesus** (see **Figure 1** and **Figure 2**)

The bigeye tuna is one of the largest tuna species. According to Reiner (1996), this species reaches a maximum of 250 cm TL although rarely are individuals over 180 cm FL caught and the normal size of catches is between 40 cm and 170 cm FL (Fonteneau and Marcille Eds. 1991). Maximum recorded weight is 210 kg (Frimodt 1995).

According to Fonteneau and Marcille (op. cit.), maximum longevity of this species could be in the vicinity of 15 years, although the maximum recorded age is 11 years (Froese and Pauly Eds. 2006).

External characteristics:

- Robust body narrowing towards the tail. Large head and eyes. Body height exceeds 25% of fork length. Maximum height is reached in the middle of the body, in the vicinity of the first dorsal fin.
- Small scales. Corselet scales are larger and thinner but the difference is slight.
- Small conical teeth in single rows.
- Two dorsal fins spaced close together. The first half of the first (spinous) dorsal fin is higher than the second (soft).
- Moderately large pectoral fin (between 22% and 31% of fork length) in large individuals (FL in the vicinity of 110 cm), but very large in smaller individuals (under 110 cm), but can be very small in the case of individuals under 40 cm.
- Large crescent-shaped caudal (tail) fin, with a strong keel on either side of the peduncle between two smaller keels.
- Second dorsal fin and anal fin with shorter radii.
- Posterior body edges feature small triangular finlets up to the base of the tail.
- First dorsal with 11-14 spines and second dorsal with 12-16 soft rays, followed by 7-10 finlets. Anal fin formed by 14 soft rays followed by 7-10 finlets. Pectoral fin with 30-36 soft rays (Richards 2006).
- Two small bifid inter-pelvic protuberances.

Colour:

- Dark blue metallic back. Lower sides and belly whitish to silver. Sides are yellowing purple.
- Finlets are bright yellow with black edges.
- Dark yellow dorsal and pectoral fins. Silver-coloured anal fin.
- Line and dot pattern in the mid-ventral region. Fewer than 8 silver-coloured vertical lines in young individuals measuring less than 1 m at the fork. The line pattern gradually disappears in adults.

- An iridescent blue line along both sides can be observed in live specimens.

Internal characteristics:

- The liver is divided into three lobes, the central one being the most developed. In individuals over 30 cm in length, the ventral surface of the liver is striated.
- 23-31 lanceolated gill rakers on first gill arch.
- Vertebrae: 18 precaudal and 21 caudal.
- Very developed swim bladder.

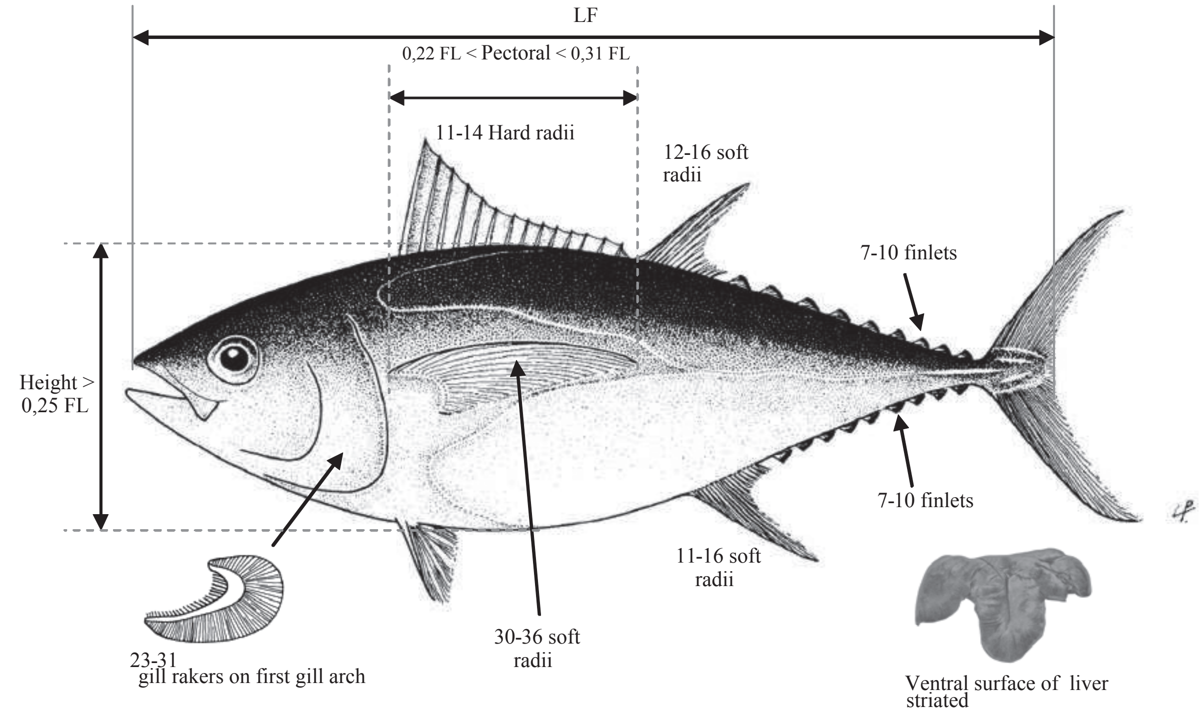

Figure 2. Schematic of outstanding features of *Thunnus obesus* (based on Collette 1995, *In* Froese & Pauly Eds. 2006. Modified by the IEO).

Differentiating characteristics between the bigeye and yellowfin tuna (*Thunnus albacares,* Bonnaterre 1788)**:**

The bigeye and yellowfin tuna are frequently caught together using surface gear and it is easy to confuse young individuals of the two species. The internal and external characteristics of the two tuna species vary with the size of individuals and catch area.

The following tables summarise the differentiating characteristics between the two species:

External characteristics	*Bigeye*	*Yellowfin*
Morphology of the body	Robust rounded body. Body outline is rounded, creating a gentle dorsal and ventral arc between the mouth and caudal peduncle. Body height is greater than 25% of FL.	Body fusiform, elongated and slender. Body outline is straight between the second dorsal and the caudal fins, and between anal and caudal fins. Body height is less than 25% of FL.
Morphology of the head and eye	Head width and length are greater than that of yellowfin of the same size. Eye diameter is greater than that of yellowfin of the same size.	Head width and length are inferior to that of bigeye of the same size. Eye diameter is less than that of bigeye of the same size.
Anal fin and second dorsal fin	Relatively short rays.	Longer rays in comparison with all other adult tuna species.
Length and characteristics of the pectoral fin *For individuals smaller than approximately 40 cm FL*	Slightly longer extending to the second dorsal fin. Thin, flexible and pointy.	Short, barely extending to the point of insertion of the second dorsal fin. Thick, rigid and with a rounded edge.
Length and characteristics of the pectoral fin *For medium-size individuals between 45 and 110 cm FL*	Long, extending past the second dorsal fin but not past the second dorsal finlet. Sharp, flexible and often curved downwards.	Short, barely extending to the point of insertion of the second dorsal fin. Thick, rigid and like a razor blade.

Colouring	*Bigeye*	*Yellowfin*
Fresh	Metallic dark blue back and yellowish-purple sides.	Shiny yellow stripe down the middle of both sides of the body.
Vertical line pattern	Straight lines. Fewer than 8 irregular vertical lines widely spaced and continuous with some dotted sections. Most are found below the lateral line.	Curved towards the ventral part. More than 10 alternate dotted and continuous lines with little separation extending from the tail to the lower part of the pectoral fin and above the lateral line.
Finlets	Yellow with thick black edges.	Shiny yellow with fine black edges.

Internal characteristics	*Bigeye*	*Yellowfin*
Morphology and appearance of the liver	Lobes of approximately the same size. Striated ventral surface.	Right lobe larger and thinner than the central and left lobes. Ventral surface not striated.
Swim bladder	Very developed filling almost all of the body cavity.	Only fills the front half of the body cavity.
Parasites	*Nasicola klawei* (Stunkard 1962) are not found in the snout cavity.	The discoidal type of *N. klawei* is found in the snout cavity of 85-95%.

External characteristics of bigeye larvae:

- Small, fresh specimens are discernible by the presence of a pattern of red marks (erythrophores) in the caudal and jaw regions: 0-2 red pigmentation marks along the upper edge of the caudal fin and 1-8 along the lower edge; 1 red mark on each side of the tip of the lower jaw (Ueyanagi 1966).
- No internal malanophores (Ueyanagi *et al.* 1997).
- No melanaphores along the upper edge of the caudal fin (Richards *et al.* 1990).
- Black pigmentation on the lower jaw (usually two spots), in larvae > 4 mm of SL (standard length); and on the upper jaw in larvae > 5 mm of SL (Richards and Potthoff 1973).
- Heavy pigmentation of first dorsal fin (Chow *et al.* 2003).

- Distinguishable from yellowfin larvae due to lack of body pigmentation in the latter species and pigmentation spots on the lower jaw: normally 2 in the case of bigeye and 1 somewhat smaller spot in the case of yellowfin.
- The size of the malanophores (black pigmentation) is small in comparison with those of *Thunnus thynnus (Linnaeus* 1758)) and southern tuna (*Thunnus maccoy*ii (Castelnau 1872)) (Ueyanagi *et al.* op. cit.).
- Young in the range of 10-21 mm TL (total length) can be distinguished electrophoretically from yellowfin (Graves et *al*. 1988).

3. Biology and population studies

3.a Habitat

Epi- and mesopelagic species generally inhabiting open waters. The main environmental factors affecting the vertical distribution of the bigeye tuna are the depths of the deep scattering layer and temperature (Maury 2005). However, other factors such as O_2 concentration are likewise important and must be borne in mind.

Temperature: optimum range is between 17ºC and 22ºC. Bigeye tuna are not found in waters where temperature exceeds approximately 29ºC (Collette and Nauen 1983). However, when the bigeye dives to great depths it is exposed to temperatures in the 5ºC range (at 500 m), i.e. up to 20ºC colder than surface water temperature. (Brill *et al*. 2005).

Depth: The bigeye exhibits a characteristic set of depth distributions and behavioural patterns. It remains within the surface layer, at a depth of approximately 50 m, during the night and is able to dive to depths of 500 m at sunrise (Brill *et al*. op. cit., Dagorn *et al*. 2000, Gunn and Block 2001) (**Figure 3)**. Depths of over 1000 m were recorded in a study on bigeye tuna conducted using archival tags in the Coral Sea (Gunn and Block op. cit.).

The bigeye typically ascends swiftly to the temperate surface layer, probably in order to regulate body temperature or possibly to compensate for oxygen deficiency (Dagorn *et al*. op. cit.).

There appears to be a positive correlation between moonlight intensity and the depth at which bigeye tuna are found, the mean depth increasing as the intensity of lunar light increases (Matsumoto *et al*. 2005).

Dissolved oxygen: the bigeye tuna is able to withstand lower concentrations of dissolved oxygen than any of the other tuna species and is therefore capable of inhabiting deeper waters (Stequert and Marsac 1989) where oxygen concentrations are under 1.5 ml l^{-1} (Brill *et al*. op. cit.), the lower tolerance limit being 0.5 ml l^{-1} (Cayré 1987).

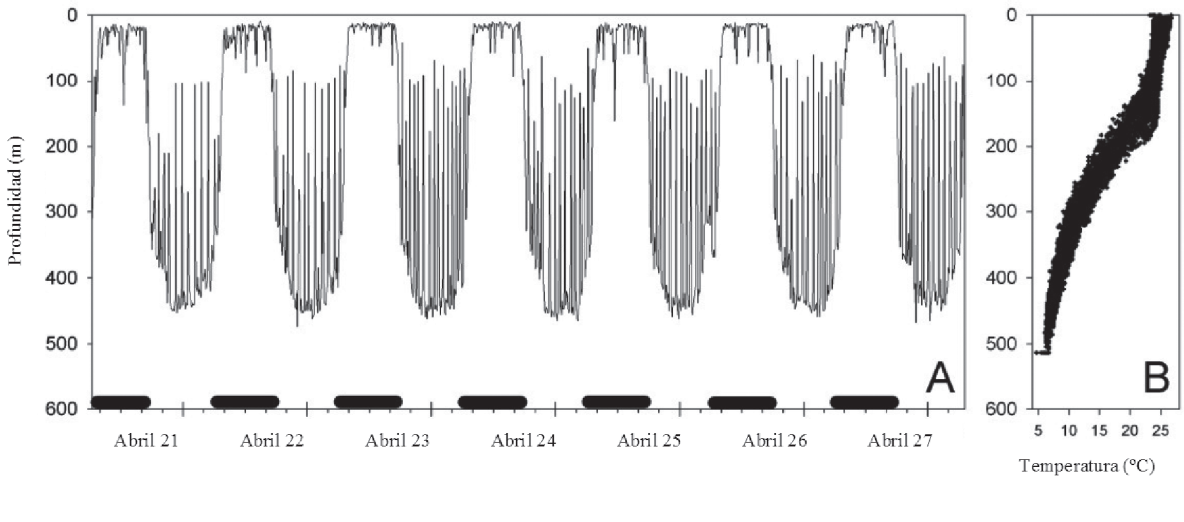

Figure 3. Archival tag depth recording of an adult bigeye tuna tagged in the Pacific Ocean off the Hawaiian Islands (Brill *et al*. 2005).

3.b Growth

The first growth parameters of the Atlantic bigeye were obtained by applying the Petersen method based on the size ranges found in longliner and surface catches calculated separately (Champagnat and Pianet 1974, Marcille *et al*. 1978) and jointly (Pereira 1984, Weber 1980). The study by Champagnat and Pianet (op. cit.), showing a size range of 60-140 cm FL, sheds light on the growth equations found in different parts of the Atlantic (Dakar and Pointe-Noire), the conclusion being that there are no significant differences between the two regions.

Other authors used direct reading methods to determine age (Draganik and Pelczarski 1984) and methods based on the marking-recapture of individuals (Miyabe 1984), showing significant differences between the growth curves for yellowfin and bigeye.

Some growth studies indicate that off the Atlantic islands there are no significant differences between the equations found for males and females (Alves *et al*. 1998, Delgado de Molina and Santana 1986, Shomura and Keala 1963).

Up until 2005, the equation adopted by the ICCAT was that proposed by Cayré and Diouf (1981) based on market data. According to these authors, there is no such thing as slow juvenile growth (sizes under 60 cm FL) nor were there any significant differences between the equations for the two tropical regions of the Atlantic (north and south). In 2005, Hallier *et al*. proposed a simple growth equation combining market data and direct reading of age in a very broad range of sizes (29-190 cm FL) which was then adjusted to the Von Bertalanffy (1938) parameters. This is the model which the ICCAT has now adopted (**Table 1**).

In **Figure 4**, Hallier *et al*. (op. cit.) show bigeye growth curves obtained by modal progression (Kume and Joseph 1966, Suda and Kume 1967), marking (Cayré and Diouf op. cit., Hampton *et al*. 1998) and direct age reading (Delgado de Molina and Santana op. cit., Draganik and Pelczarski op. cit., Gaikov *et al*. 1980) in the Atlantic and Pacific Oceans.

Table 1. Growth parameters used by the ICCAT for bigeye tuna (L_t in cm, t in years).

Growth equation	*Authors*	*n*	*Length range (FL in cm)*	*Methodology*	*Area*
$L_t = 217.3\left(1-e^{-0.18}\right)^{(t+0.709)}$	Hallier *et al*. (2005)	625 markings 255 otoliths	37 – 124 cm (markings) 29 – 190 cm (otoliths)	Reading of otoliths and markings	Eastern Atlantic (sexes pooled)

**Where Lt =length of the individual at age t.*

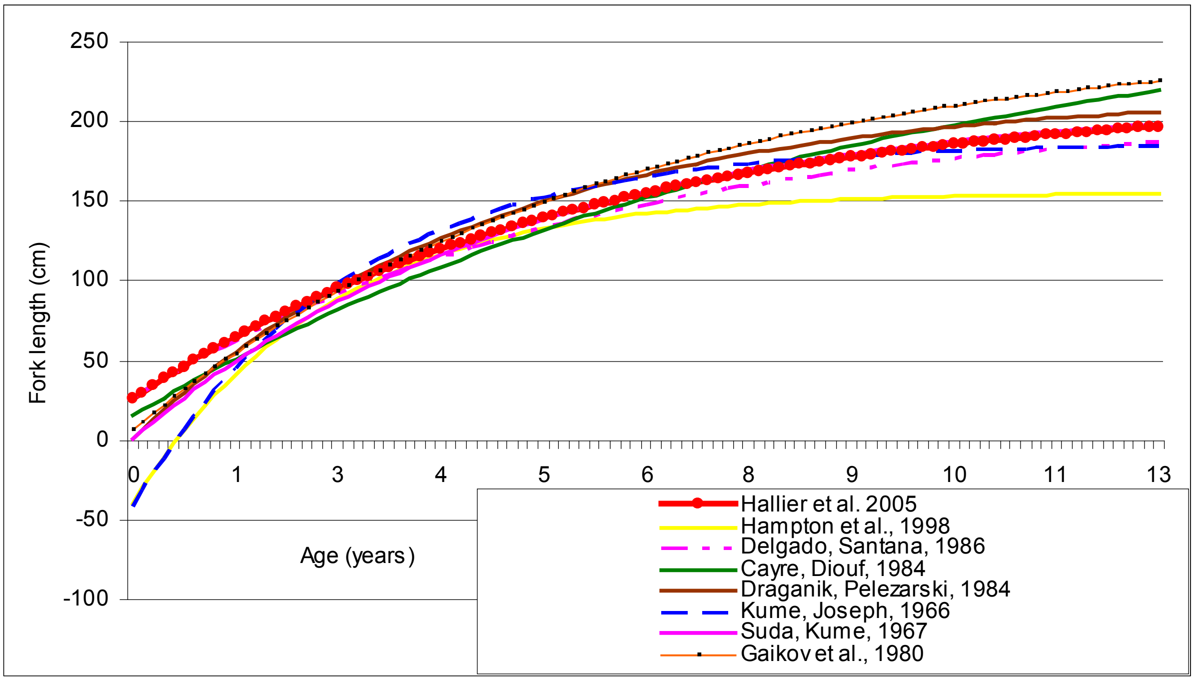

Figure 4. Comparison of some Atlantic and Pacific Ocean growth curves proposed by several authors (Hallier *et al*. 2005).

3.c Biometric relationships

3.c.1 Size-weight equations

The size (FL)-weight (W) equation in use since 1982 is that developed by Parks *et al*. with 3,186 individuals from East Atlantic fisheries and size range of 37-210 cm FL. The results obtained were very similar to those previously published by Lenarz (1971), and those furnished by the studies conducted by Chur and Krasovskaya (1980). The results from the Parks *et al*. (op. cit.) study show that there may be significant differences in size-weight ratios depending on the area, season of the catch and sex.

3.c.2 Conversion factors between weights and sizes

Recent works such as that by Liming *et al*. (2005a) have demonstrated new size-weight and round weight (RWT)-dressed weight (DWT) relationships for males, females and both sexes combined.

Morita (1973) and Choo (1976) established conversion factors between round weight and gutted weight (GWT), the accepted value being 1.16, obtained by the first of these authors. Choo's study showed that the said factor varies depending on fish size.

As for FL-DL_1 (pre-dorsal length) ratios, special mention should be made of the work done by Champagnat and Pianet (1974) and Choo (op. cit.).

Other relationships such as fork length curve-fork length segment (FL), operculum to caudal keel (OCKL) length- fork length, have been developed and published by different authors such as Lins Oliveira *et al*. (2005) based on individuals caught in Brazilian waters and Choo (op. cit.) with individuals from the Gulf of Guinea. All of these equations have clear practical applications, however for practical reasons only those mostly commonly used are cited in this manual.

Table 2. Different biometric relationships for bigeye tuna currently used by the ICCAT.

Equations and conversion factors	Authors	n	Length range (cm)	Area
Size-Weight				
$W = 2.396 \times 10^{-5} \times LF^{2.9774}$	Parks *et al*. (1981)	3 186	37 – 210 cm (FL)	Eastern Atlantic
Weight-Weight				
$RWT = 1.16 \times GWT$	Morita (1973)	99	50.2 – 175.5 cm (FL)	Atlantic
Size-Size				
$LD_1 = -21.451 + 5.28756\sqrt{LF}$ *Si LD_1 > 48:* $LF = \left[\frac{LD_1 + 0.5 + 21.45108}{5.28756}\right]^2$	Champagnat and Pianet (1974)	2 853	13 – 48 cm (DL_1)	Eastern Atlantic

* *Where W=weight; FL=fork length; RWT=round weight); GWT=gutted weight); DL_1=pre-dorsal length*

3.d Maturity

The only data available for the Atlantic are those obtained by Matsumoto and Miyabe (2002) showing size at first maturity, with over 50% mature females, at 110 cm in Dakar waters and with 53% mature females the size is 100 cm in Abidjan waters.

Most of the studies conducted in Pacific waters put the minimum size of the bigeye tuna at sexual maturity in the vicinity of 100 cm. In the western Pacific, 50% of the females reproduce with a size of first maturity of 135 cm and a minimum sexual maturity size of 102 cm (Schaefer *et al.* 2005).

Table 3. First maturity sizes in the Atlantic.

Maturity	*Reference*	*Area*
50% mature females measuring 110 cm	Matsumoto and Miyabe (2002)	Dakar
53% mature females measuring 100 cm	Matsumoto and Miyabe (2002)	Abidjan

3.e Proportion of sexes

Generally speaking, most studies have been conducted based on fish caught using longline gear (Gaikov 1983, Sakamoto 1969) and coincide in showing a greater proportion of males above a certain size in all of the Atlantic areas studied.

Gaikov (op. cit.) studied the seasonal dynamics of maturation and compared the sexes with a sample size of 31 804 bigeye tuna individuals from different parts of the Atlantic from 1965-1975. This study shows that males are, in fact, more numerous than females except in the north-east Atlantic.

Pereira (1985) noted that males outnumber females among individuals under 70 cm FL and over 155 cm FL, although the sex ratio is 0.92 (male/female) for most sizes indicating a slight overall predominance in the number of females. In 1987, this same author published a survey based on 1,480 individuals between 1981-1986, obtaining a proportion of 0.9, indicating a slight predominance of females except amongst individuals exceeding 160 cm FL and small individuals where males are predominant.

In 2003, Miyabe indicated that the proportion of males increases as size increases, basically in size categories of 160 cm FL and under 100 cm FL. In this case, 134,000 individuals were analysed between 1987 and 2001 and the sex ratio was generally above 0.5 (males/total) (**Figure 5**); although in some areas and seasons, more females than males were found. The predominance of males is especially prevalent in tropical waters and these results generally show figures below those found in previous studies.

At the *Symposium on the Bigeye Year Programme* (Anon. 2005) the conclusion was reached that all available observations point to a numerical predominance of males in the over 150 cm FL group except in the waters to the south of Brazil.

And finally, a study published in 2005 by Fonteneau *et al*. indicates that in the Atlantic Ocean the sex proportion patterns by size are similar up to 130 cm FL, while males are slightly more dominant as from 135 cm FL.

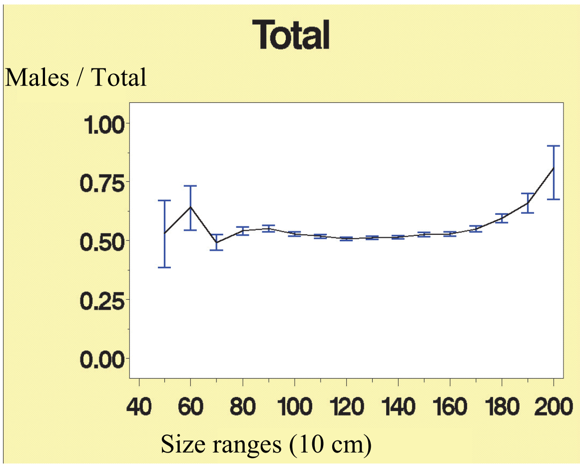

Figure 5. Proportion of sexes with a 95% confidence level for bigeye caught using Japanese longline gear in the Atlantic. Size ranges are 10 cm FL (Miyabe 2003).

3.f Reproduction

Spawning

Bigeye spawning takes place mostly at night. It is estimated that the bigeye tuna spawns from 18:00 until after midnight, depositing eggs daily (Matsumoto and Miyabe 2002). Similar results were obtained in the Pacific Ocean (Nikaido *et al*. 1991). This tendency to spawn at night may be to minimise depredation or the danger of ultraviolet rays (Schaefer 1996).

Spawning takes place in areas of great biological productivity: near the borders of localised eddies and local seamounts, frontal regions of the equatorial current and the northern branch of the southerly trade current (Rudomiotkina 1983).

Spawning takes place throughout the entire year in a vast zone in the vicinity of the equator with temperatures above 24ºC from the coast of Brazil to the Gulf of Guinea. Egg-laying is particularly prevalent: from January to June to the south of Brazil, from December to April in the Gulf of Guinea and during the third quarter of the year in a wide area near the equator off the north-east coast of Brazil and Venezuela (Cayré *et al.* 1988). However, in the north of the eastern Atlantic (Cape Verde Islands, Senegal), the spawning period is reduced to the months of July to September and in the south (Congo-Angola) from November to February (Rudomiotkina op. cit.).

Eggs and larvae

Eggs are pelagic and not adhesive. They have a single fatty globule (Kikawa 1953) and their diameter ranges from between 0.8-1.2 mm at an advanced stage of development (Nikaido *et al*. 1991). Larvae develop 86 hours after spawning (Yasutake *et al*. 1973).

Bigeye larvae are most frequently found where temperatures are above 28ºC, with salinity levels of 33.8-36.0%, and only very rarely in areas where temperatures are below 24ºC. They are identifiable by pigmentation in the middle region of the brain, the viscera, jaw tips and the ventral edge of the caudal zone (Ambrose 1996, Richards 2006).

The number of eggs per individual is estimated at between 2.9 – 6.3 million yearly (FIGIS-FAO, *Fisheries Global Information System*).

3.g Migrations

The bigeye is a species very prone to migration. Marking-recapture data show that the bigeye travels faster than the yellowfin and its speed is on a par with the skipjack. It is also characterised by a series of seasonal movements depending on age groups (Bard *et al.* 1991) and the nature of the migrations (trophic or genetic).

In the eastern Atlantic spawning areas, young individuals (30-70 cm FL) tend to gravitate towards the equatorial area (Gulf of Guinea) forming mixed schools with young skipjack and yellowfin tuna. The young remain in this area until spring when they begin to migrate towards the tropics (Bard *et al*. op. cit., Hallier 2005). They travel along the coast of Africa from Cape Lopez to Senegal and Mauritania (Miyabe 1987a, 1987b). Some continue towards the Azores, Canary Islands and Madeira (Bard and Amon Kothias 1986), at a speed of 10 miles/day or migrate from the interior of the Gulf of Guinea towards the Central Atlantic. Pre-adults (70-100 cm FL) migrate in a northerly (Senegal and Sherbro) and southerly direction (Angola) from the Gulf of Guinea. They are prevalent in baitboat fisheries and are caught in great number between April and September in Cape Lopez and between November and January in Liberia. Individuals over 100 cm FL (adults) are caught throughout the whole of the tropical and sub-tropical Atlantic with longline gear. A proportion of the individuals marked in the Canary Islands migrated towards the southern sub-tropical zone following the coast (Delgado de Molina *et al*. 2002, 2005b) and towards the central Atlantic for trophic reasons. They also migrate to the equator to reproduce (genetic migrations). During the main rod-and-line fishing season in Dakar (August to December) very few bigeye migrate north (Hallier op. cit.). During the months of October- November, the bigeye which had migrated towards the archipelagos return south.

Marking studies show trans-Atlantic migrations from the Gulf of Guinea to the north of Brazil and movements from the Gulf of Guinea adjacent to the African coastline (Pereira 1995).

Only a few studies, such as Zavala-Camin 1977, have been conducted in the western Atlantic. This author notes that the bigeye migrates towards the south and south-east of Brazil when conditions are favourable.

Figure 6 shows the migration routes followed by bigeye tuna marked and then recaptured in the Atlantic Ocean. As in the case of skipjack and yellowfin, trans-Atlantic migrations have been recorded from the coast of America to the Gulf of Guinea. In the eastern Atlantic, migrations have been observed from the Gulf of Guinea to fisheries in the north, such as the Azores, as well as to the south (Angola), and their corresponding return routes. In the western Atlantic (where far fewer bigeye have been marked) wide-ranging migrations are observed along the North-American coast with a few individual reaching a latitude of 50ºN.

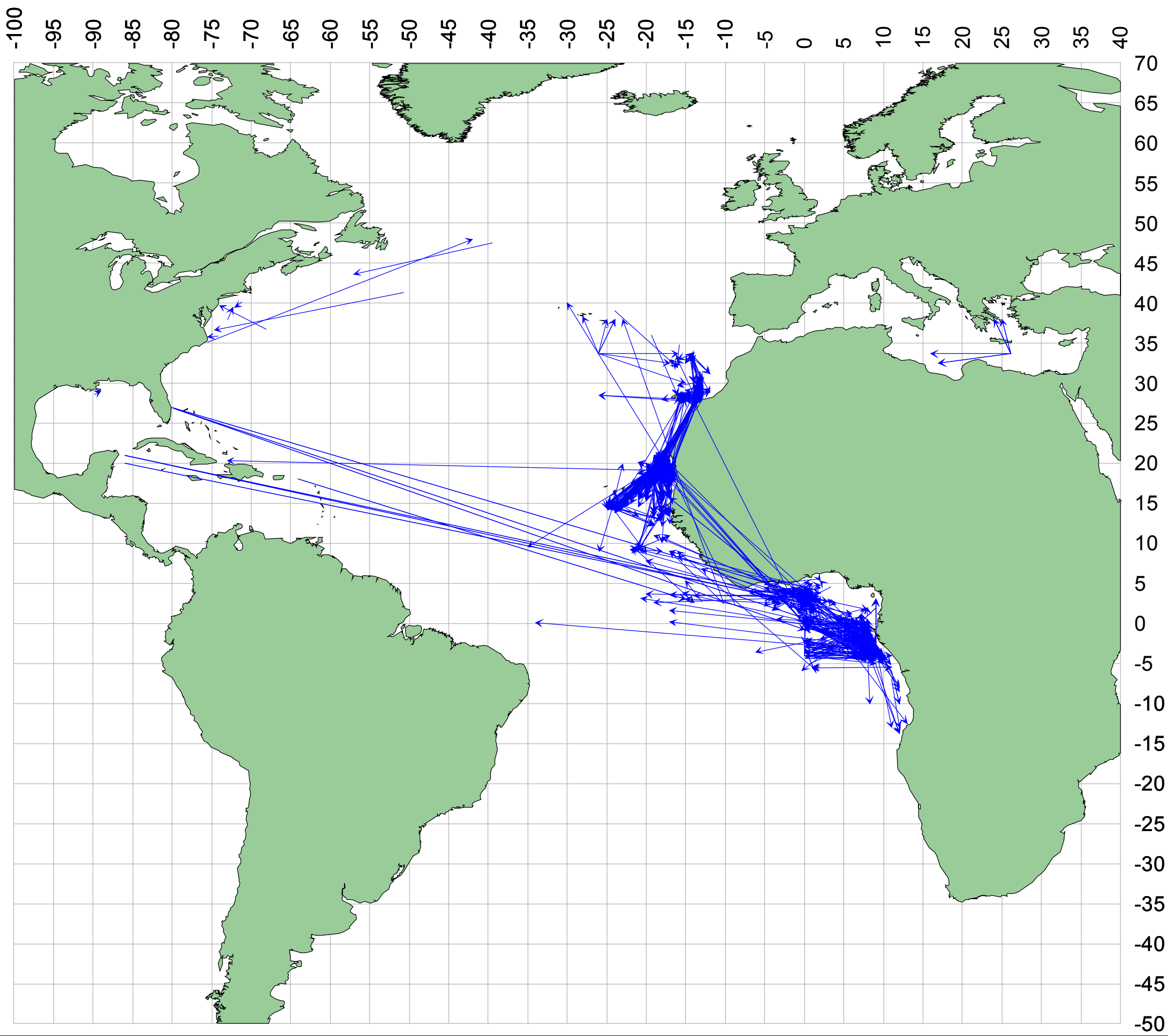

Figure 6. Horizontal migrations of 3,021 bigeye tuna which were marked and recaptured (ICCAT Secretariat).

3. h Diet

Tuna are opportunistic predators meaning that their diet varies in time and space. According to Lebourges-Dhaussy *et al*. (2000) micronekton is the largest component of tuna's oceanic diet. The bigeye feeds on oceanic mesopelagic communities (migratory and non-migratory), cephalopods, euphausiaceans and mesopelagic fishes and therefore its diet is less affected by latitude or distance from the coast than that of other tuna (Bertrand *et al*. 2002, Dagorn *et al.* 2000).

There are recordings of bigeye moving vertically to forage on organisms from the deep scattering layer (ranging in depth from 200 m to 500 m during the day depending on the area). In their study, Dagorn *et al.* (op. cit.) quote a personal communication from F.X. Bard concerning the finding of cephalopods (*Japetella diaphana*, Hoyle 1885) and some fish species (*Argyropelecus aculeatus*, Valenciennes 1850; *Myctophum selenops*, Taning 1928; *Scopelarchus analis* (Brauer 1902); *Diaphus mollis*, Taning op. cit.) as part of the bigeye's diet.

Juvenile bigeyes have been observed feeding on small-sized mesopelagic fish *Vinciguerria nimbaria* (Jordan and Williams 1895) (Ménard *et al.* 2000b) in the eastern Atlantic.

3.i Physiology

Like all tuna, the bigeye is a highly active species. Tuna differ from all other fish in their ability to retain metabolic heat in the red muscle and in other areas of the body such as the brain, eyes and viscera (local endothermia), a high metabolic rate and frequency-modulated cardiac output. These specialised features equip tuna for sustained rapid swimming, minimising the thermal barrier to exploitation of their habitat while allowing them to expand their geographic distribution into high latitudes and considerable ocean depths (Graham & Dickson 2004, Dickson & Graham 2004).

Tuna, including the bigeye, possess a highly-developed circulatory system including a system of counter-current blood vessels (*retia mirabilia*), which reduces muscle-generated heat loss and improves the efficiency of oxygen exchange (Graham & Dickson op. cit.). Coetaneous vascularisation is more developed in the *Thunnus* genus and is indicative of diminished importance of the central vascular network and its associated *retia* in adult tuna. Bigeye lack a developed central *retia* but rather has a visceral heat exchange system only found in this species and the bluefin (Sharp and Pirages 1978, Graham and Diener 1978).

The ability of tuna to retain heat is also affected by size and developmental stage. The greater mass of adult tuna allows them to retain more heat by thermal inertia than young specimens (Brill *et al.* 1999, Maury 2005).

The bigeye has developed a characteristic allowing it to tolerate low oxygen levels (Lowe *et al.* 2000) while simultaneously maintaining an elevated metabolic rate owing to the high oxygen affinity of the blood of this species providing an effective system for high rates of oxygen extraction, even in environments where oxygen concentration is low (Brill *et al.* op. cit.). Thanks to this adaptation, it can dive to greater depths than other tuna such as the yellowfin or skipjack.

P_{50} (partial pressure of oxygen required to reach 50% saturation) ranges from 1.6 to 2.0 kPa (12 to 15 mmHg), in temperatures of between 15 and 25ºC, with 0.5% CO_2 (Lowe *et al.* 2000).

The swimming motion of tuna is characterised by a system of propulsion with minimal lateral undulation and concentration of thrust in rapid oscillation of the caudal fin. Tuna are the only teleosts to swim in this way (Graham & Dickson op. cit.).

3.j Behaviour

Like all tuna, bigeye are gregarious and tend to form schools, either independently or in association with drifting objects, marine animals or seamounts.

Free schools (not associated to any object) are typically formed by large individuals of the same species (Ménard *et al*. 2000a), although bigeye may also be found together with other tuna species such as the skipjack (*Katsuwonus pelamis*, Linnaeus 1758), albacore (*Thunnus alalunga*, Bonnaterre 1788), or the yellowfin (Pereira 1996).

In the eastern Atlantic, bigeye tuna are frequently associated with a large variety of drifting objects, including dead whales, or with some living animals. Ariz *et al.* (1993, 2006) noted that the predominant species in catches is the skipjack, which accounts for around 70%, followed by bigeye and yellowfin accounting for about 15% each. Bigeye schools associated with objects are formed primarily of small individuals (under 5 kg.) although there is a significant proportion of large-sized individuals.

No trophic function for tuna species has been observed in the drifting objects. Small tuna congregate beneath the object at night and may form free schools during the day to feed, normally on *V. nimbaria* (in the eastern Atlantic), a species not associated with objects (Ménard *et al*. 2,000a).

Object-associated schools may include other species such as wahoo (*Acanthocybium solandri* (Cuvier 1832)), istiophoridae, balistidae, rainbow runner (*Elagatis bipinnulata* (Quoy & Gaimard 1825)), coryphaenidae, kyphosidae, some shark species, cetaceans and turtles. These species are also found in free schools, as reported in the work of Delgado de Molina *et al*. (2005b), which also suggests that more species, in terms of both weight and numbers, are attached to object-associated schools than to free schools.

In the Canary Islands and Senegal a kind of fishing is practised which is known as "*pesca sobre manchas*", in which the fishing vessel acts as a floating object. This kind of association between school and fishing vessel can go on for several months, during which several vessels fish the same school, even outside the normal fishing season (Ariz *et al*. 1995, Delgado de Molina *et al.* 1996, Fonteneau and Diouf 1994, Hallier and Delgado de Molina 2000).

According to Pereira (op. cit.), in the months from August to October, in Azores waters bigeye tuna associate as single-species schools with whale sharks (*Rhincodon typus*, Smith 1828) and in mixed-species schools with skipjack. Birds are frequently associated with schools of tuna, helping fishing vessels to find the latter. Data collected by observers on baitboat fishing vessels in waters of the Azores indicated that the most frequent type of association with other animals was with birds (*Calonectris diomedea* (Scopoli 1769)), and in the case of bigeye, at a frequency rate of 87.3% (Pereira 2005).

Multi-specific tuna schools congregate over seamounts according to data on catches by purse seine tuna fisheries in the eastern Atlantic (Ariz *et al.* 2002). The predominant species is skipjack (59%), followed by bigeye (22%) and lastly yellowfin (19%). The range of variation is very broad, but with due allowance for the year and the location of the seamounts, the specific composition of catches tends to be similar to that obtained in catches associated with drifting objects. The associations observed around seamounts in the Azores may be of trophic origin (Pereira op. cit.).

There is evidence to suggest that objects affect the dynamics and the structure and feeding ecology of tuna schools, and possibly act as a barrier to natural movements and migrations (Marsac *et al.* 2000). Moreover, these effects seem to be stronger in the case of small tuna species or the young of large tuna (Fonteneau *et al*. 2000); this augments the vulnerability and the rate of capture of young stocks and could have serious repercussions on the population structure and the future breeding potential of these species.

Small bigeye are caught by purse seine gear in the warm equatorial surface waters while most adults are caught by longliners indicating the existence of vertical stratification where adult bigeye schools remain at greater depths than schools of juveniles (Fonteneau and Pallarés 2005).

3.k Natural mortality

Natural mortality (*M*) is one of the most important parameters in assessing populations but is also one of the most difficult to estimate.

In the case of bigeye and other tuna species, the natural mortality rate is age dependent (Fonteneau and Pallarés 2005). In the most recent evaluations conducted by ICCAT, the *M* values used are higher for young individuals during the first two years of life (0.8) and lower (0.4) for older individuals (Anon. 2005a).

Other authors use different natural mortality rates during the course of the life cycle. According to Hampton (2000), natural mortality patterns should be broken down into three stages: early mortality, stable mortality and senescence (U-shaped curve) because values vary according to the ecology of the species or the energy expended on biological functions (Anon. 2006).

Fonteneau and Pallarés (op. cit.) also support the hypothesis adopted in 1984 (Anon. 1984) which holds that the natural mortality rate of small individuals is similar to that of the species with which they share habitats and form groups.

A specific natural mortality rate can likewise be determined by sex, being higher for females owing to energy expended during spawning (Anon. 2006, Harley and Maunder 2003).

The immediate mortality rates found for juveniles (57 cm FL) correspond to previous estimates and are in the 0.62-0.67/year range (Gaertner and Hallier 2003); these same authors suggest an annual *M* of 0.58 for young bigeye in the area of Mauritania and Senegal (Gaertner *et al*. 2004).

Fagundes *et al*. (2001), using an empirical equation by Rikhter and Efanov (1976) to calculate natural mortality rate, came up with values of 0.53, 0.41 and 0.32 per year for individuals aged 3, 4 and 5 respectively.

4. Distribution and fishing

4.a Geographical distribution

Bigeye are widely distributed in the tropical and subtropical waters of the Atlantic, Indian and Pacific Oceans. They are not present in the Mediterranean Sea (Collette and Nauen 1983). Geographical limits are 55º-60ºN and 45º-50ºS. This wide distribution accounts for the number and variety of fisheries that have developed all around the world (**Figure 7**).

Young individuals are most typically found in the equatorial region while adults spread out to higher latitudes.

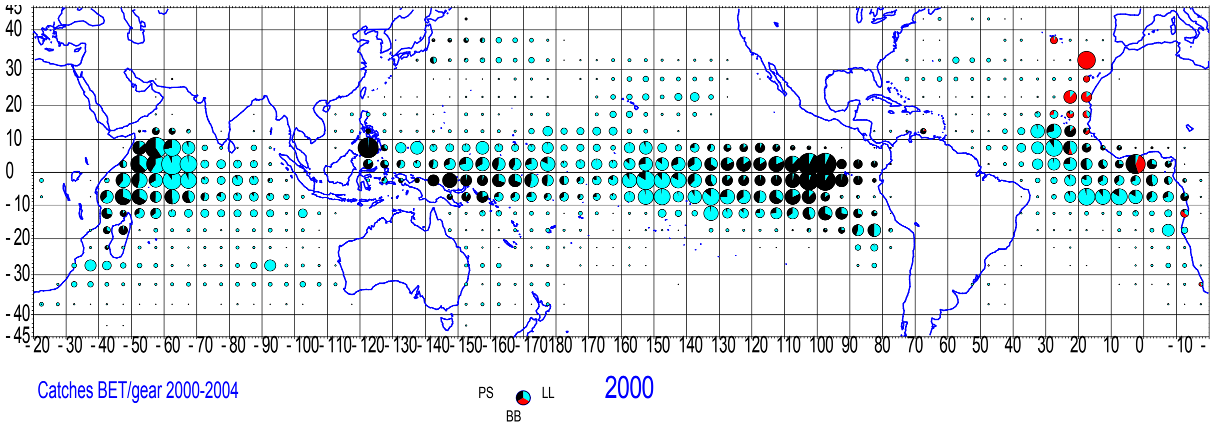

Figure 7. Bigeye tuna zones fished by several fleets between 2000 and 2004: longline (in blue, LL), purse seine (in black, PS) and bait boat (in red, BB) (courtesy of Alain Fonteneau 2006).

Distribution in the Atlantic Ocean: in the eastern Atlantic from Ireland to South Africa, and in the western Atlantic from the south of Canada to northern Argentina.

4.b Population / Structure of stock

A number of different methods have been employed to identify populations and determine the population origin of bigeye catches including marking-recapture, phenotype studies (morphometry) and genetic-marker analysis: mitochondrial DNA (mtDNA) and nuclear DNA (nDNA).

Marking studies have revealed transatlantic migrations from the Gulf of Guinea to the Central and eastern Atlantic (Pereira 1995), considered as one single stock since the middle of the 1980s (Turner 1998). The bigeye spawns on both side of the Atlantic at latitudes near the equator (10ºN-10ºS).

In 1998, Alvarado Bremer *et al.* analysed the mtDNA sequences of 248 individuals from the three oceans and found genetic differences between the Atlantic and Indo-Pacific. The homogeneity of the Atlantic bigeye population was noted by Chow *et al.* (2000), who once again analysed two mtDNA sequences from different geographical origins using restrictase (ACTO as quasi-diagnostic loci and D-loop as variable loci). This analysis showed that there was no genetic flow between the Atlantic and Indian Oceans.

Under the umbrella of the BETYP project (Anon. 2005), Martínez and Zardoya (2005) analysed the genetic structure of individuals from different Atlantic regions (Gulf of Guinea, Somalia, Canada, Canary Islands and the Azores) and one region of the Indian Ocean. Once again based on the mtDNA sequence variance study, no genetic differences were observed between samples coming from the different geographical areas of the Atlantic Ocean and results were stable. The existence of a specific Atlantic clade was, however, confirmed.

In terms of the current management of bigeye tuna, the hypothesis of a single bigeye stock for the entire Atlantic is still accepted based on this work on genetics and on other evidence such as the space-time distribution of the fish and movements of marked individuals. However, other possible scenarios such as stocks to the north and south, (Anon. 2005a), should not be ruled out.

4.c Description of fisheries: Catches and effort

This stock has mainly been caught using three gears (longline, bait boat and purse seine) and by many countries in its entire area of distribution (**Figure 8**), longline accounting for the greatest proportion of the total catch (65% from 1999 to 2003) (Anon. 2005b).

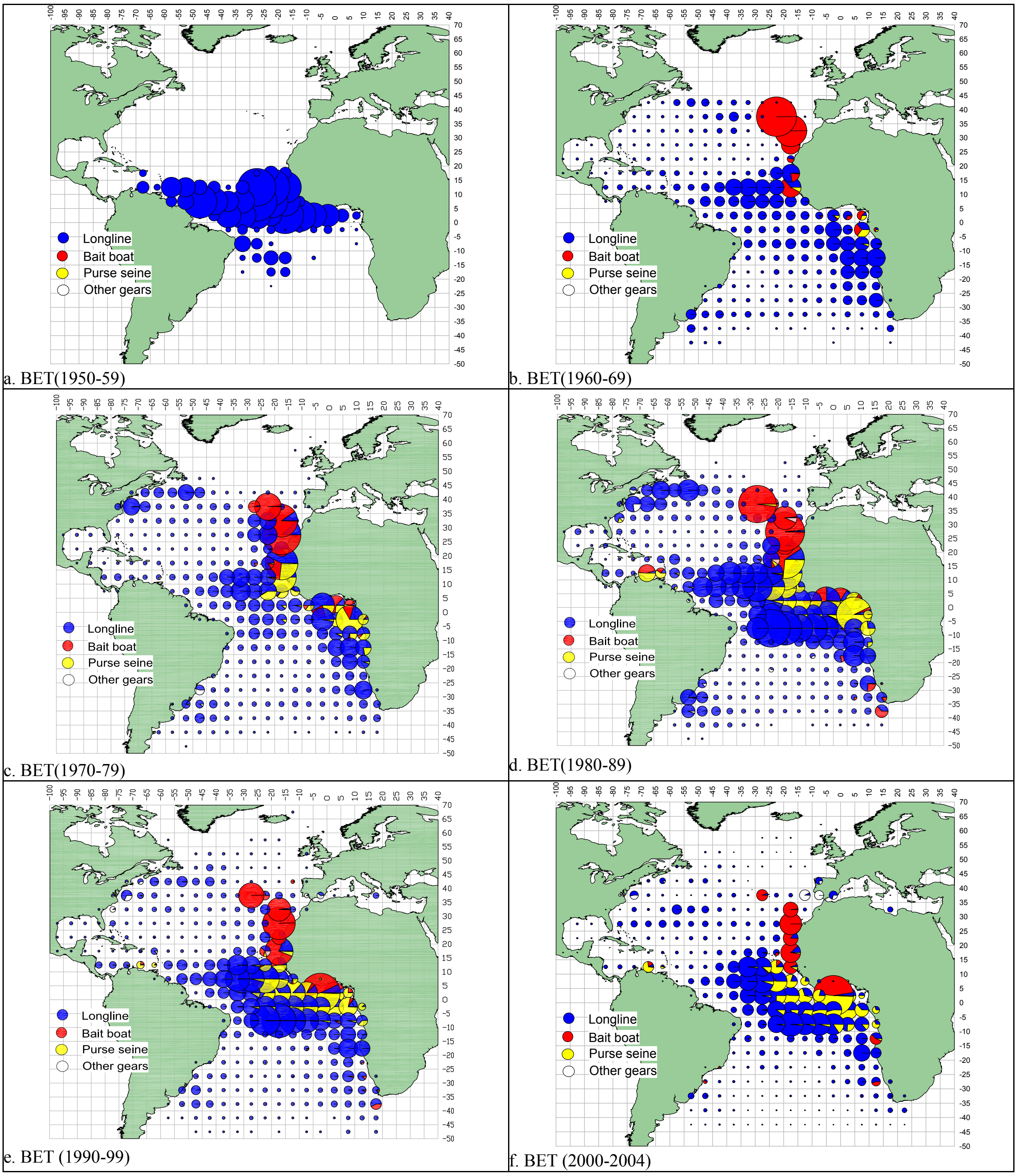

Figure 8. Geographical distribution of bigeye catches by principal gears and decades (ICCAT Secretariat).

There are two major **longline fisheries** (Japan and Chinese Taipei) whose fleets accounted for nearly 44% of the total catch in terms of weight in 2004. China and the Philippines have also begun to fish in recent years (1993 and 1998 respectively) (Anon. 2005b).

The Japanese fishery began in 1956 focusing on yellowfin and albacore but by the end of the 1970's their target species had changed to tropical water bigeye and tuna and southern tuna in temperate waters. As a result, the longliners specifically focusing on bigeye concentrated their efforts on the tropical eastern Atlantic with the introduction of deep longline gears (Anon. 2005a).

Longline fishing effort was on the rise during that same period from 45 million hooks at the end of the 1970's to a peak of 120 million in 1996. Between 2000 and 2001, the number of hooks fell from 99 to 78 million. The

Japanese longline catch was on the rise going from 15,000 t in the 1960's to 35,000 t at the beginning of the 90's when the trend reversed, falling to 15,200 t in 2004 (Anon. 2005a).

In the case of Chinese Taipei's longline fleet, bigeye was one of the most important species as from 1990, catches growing from 8,000 t at the end of the 1960's to 20,000 t at the end of the 1990s. As from 1998, annual catch limits were set at 16,500 t and 125 vessels but the introduction of 10 vessels sailing under flags of convenience kept catch levels over the 18,000 t level for 2002-2003 (Anon. 2005a).

The activity of illegal, undeclared and unregulated longliners (INN) flying under flags of convenience seems to have commenced at the beginning of the 1980s and has become quite significant since that time. Unreliable estimates have been made of the catches of these vessels. Estimates indicate a peak in undeclared catches of 25,000 t in 1998 and a sharp decline since that time. This decline reflects more conscientious reporting by countries/organisations involved in these activities and efforts on the part of longliner countries which have collaborated in reducing the number of INN vessels (Anon. 2005a).

Bigeye sizes in longline catches vary from medium to large **(Figure 9)**, average weights being in the 45-50 kg range (Anon. 2005a).

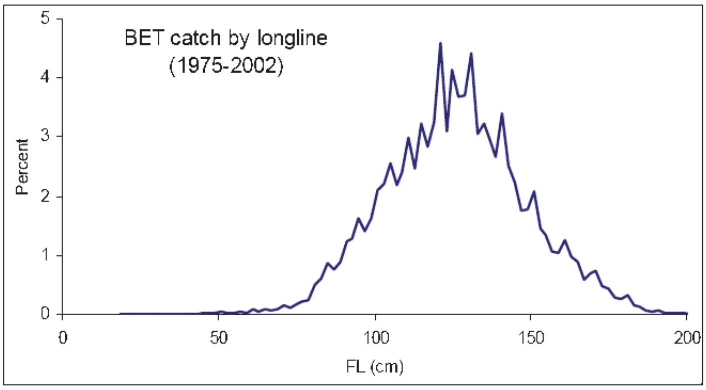

Figure 9. Distribution of bigeye sizes in longline catches.

The main **baitboat fisheries** are found off the shores of Ghana, Senegal, the Canary Islands, Madeira and the Azores, dating back to the beginning of the 1960's (Anon. 2005a).

Catches in Ghana are mainly of small tuna, including bigeye, moving in free schools. There are a number of fisheries along the African coast. One of these, based off of Dakar, began operation in 1956 in the coastal zones of Senegal and Mauritania where bigeye fishing is seasonal running from March to November (Anon. 2005a).

Since approximately 1991, Ghanaian purse seine and baitboat fisheries have been using a technique involving fish aggregation devices (FADs). Similarly, baitboat fleets in Senegal and the Canary Islands fish on banks of tuna in a variant of baitboat fishing in which the vessels themselves are used as FADs. The use of these techniques has apparently improved fishing efficiency and has helped to increase catches of bigeye tuna (ICCAT 2003, Fonteneau & Diouf 1994).

In several eastern Atlantic archipelagos the target tuna species vary by time of year but the average bigeye weight is in the vicinity of 19-20 kg, the most abundant catches being made in the months of April to July in the Azores and from March to July in Madeira. The last several years have witnessed a decline in catches made in the area of Madeira and the Azores which is most likely due to environmental factors. In the Canaries, the peak fishing season is from March to October (Anon. 2005a).

The total baitboat fishery catch for the 1980's has been established as between 7,000 and 15,500 t, the highest levels reached in 1985 with 17,651 t. In the 1990/s, catches remained over 16,000 t, with peak levels of 25,552 t in 1995. As from the year 2000, catches declined considerably reaching a total of 9,932 t in 2003 and 14,107 t in 2004 (ICCAT. 2006).

Bigeye sizes in baitboat catches vary from small to large, average weights being in the 20-30 kg range (Anon. 2005a).

Figure 10 shows size the distribution of bigeye catches in baitboat fisheries in Dakar.

Número

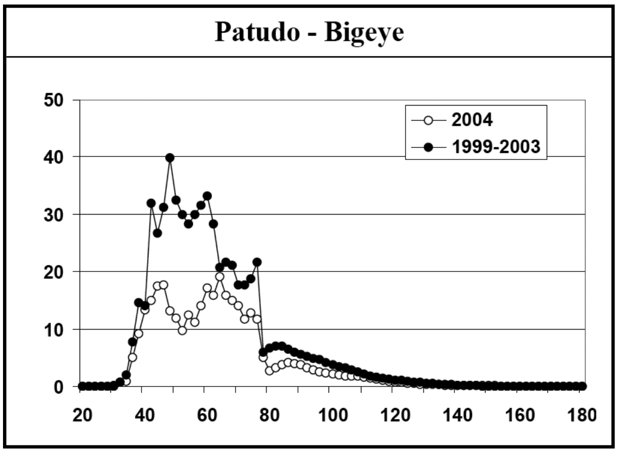

Figure 10. Size distribution of bigeye catches (in number) at the Dakar baitboat fishery (Pianet *et al.* 2006).

Tropical **purse-seine fisheries** operate in the Gulf of Guinea off the coast of Senegal in the eastern Atlantic with fleets comprised of vessels from EC-France, EC-Spain, Ghana and other vessels of European ship owners sailing under flags of convenience. The total number of European and associated purse-seine vessels has decreased from 71 vessels in 1990, levelling off to 40-45 as from 1998. Some of these purse-seiners are associated with support vessels for fishing on floating objects (Anon. 2005a).

The western tropical purse-seine fisheries are dominated by the Venezuelan fleet although bigeye catches are very small (under 500 t/year) (Anon. 2005a).

Total purse-seine fishery catches in the 1980's was over 6,000 t, with a maximum of 16,063 t in 1984. Catches increased in the 1990's with the introduction of FADs in 1991; over 15,000 t with a peak of 30,074 t in 1994. Between 2000 and 2004, catches fluctuated between 22,237 t in 2003 to 13,388 t in 2004 (ICCAT 2006).

Bigeye sizes in purse-seine catches were small, average weights being in the 3-4 kg range (Anon. 2005a).

Figure 11 shows the size distribution of bigeye caught with purse-seine gear with floating objects and free-school.

Objects

Free school

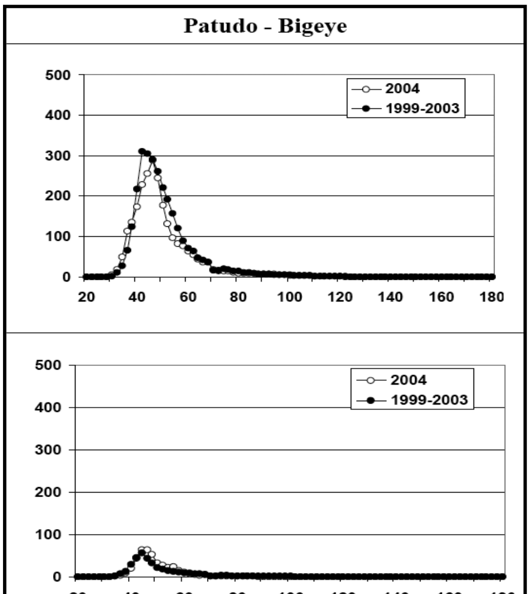

Figure 11. Size distribution of bigeye catches (in number) at purse-seine fisheries (Pianet *et al.* 2006).

The total annual catch for the three fisheries rose until the middle of the 1970's reaching 60,000 t and then fluctuated for the subsequent 15 years. In 1991 it reached 95,000 t and continued to rise until reaching its historic maximum level of close to 130,000 t in 1994. Since then, the dominant trend in the fisheries observed has been a generalised decline in catches for all fishing gears following the maximum amount reached in 1999 (121,000 t). In 2004, the total declared catch was 72,000 t which was the lowest since 1989 representing a fall of 12,000 t vis-à-vis 2003 (ICCAT 2006).

The fall in longline catches is probably mainly due to a fall in estimated INN catches and Japanese catches while other countries/organisations maintained catches at a stable level. Other gears (purse-seine and baitboat) also followed a similar declining pattern but were more variable. The fall in Japanese catches is related to a reduction in fishing effort and a declining CPUE (catches per unit effort) in the main tropical water fishing grounds (ICCAT 2005).

Some changes have taken place as concerns fisheries targeting bigeye. One is the upward trend in baitboat fishery catches (the Azores and Madeira) in the wake of four years of low catches (2000-2003). Another change was also observed as from approximately 2001 in the fishing grounds of the Japanese longline fleet, part of which has been fishing the north-central Atlantic region between 25º-35º N and 40º-75º W. In addition to the fishery changes mentioned in the foregoing, several countries significantly increased their catches in 2004 although the rise in absolute terms is small: Philippines (1,850 t), Venezuela (1,060 t) and Korea (630 t). The catches reported by Chinese Taipei for 2003 are considered underestimates. Chinese Taipei will re-estimate its bigeye catches for 2003 in the near future. The new estimate is expected to be higher than the catch reported (ICCAT 2005).

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