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FISHERY AND BIOLOGY OF BLACKFIN TUNA *THUNNUS ATLANTICUS* OFF NORTHEASTERN BRAZIL

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ABSTRACT Blackfin tuna, *Thunnus atlanticus*, is the target species of a handline artisanal fishery off northeastern Brazil in September–January, but it is also caught by anglers and as by-catch in industrial fisheries. The population structure, morphometric relationships, mortality, reproduction, and fishery dynamics were studied during 2 fishing seasons (1996 and 1997). The maximum length and weight observed were 87 cm FL and 10 kg W_d, respectively. Males were larger and predominant (1.9:1). The length at 50% maturity was 49.8 cm FL for females and 52.1 cm FL for males. This species uses the area for reproduction, although a spawning peak was not observed. The length at first capture (58.1 cm FL) was higher than the length at 50% maturity. The total, natural, and fishing mortality rates were 2.34, 0.94, and 1.40 year^{-1}, respectively. The total length-fork length and the total length-standard length relationships were TL = 1.35369 + 1.0462 FL and TL = 6.37742 + 1.0544 SL, respectively (sexes grouped). The length-weight relationship estimated for both sexes was $W_d = 0.00003\ FL^{2.8569}$. Annual catches decreased from 154 t year^{-1} in the 1970s to 33.5 t year^{-1} in the 1990s. It seems that there was not much change in the structure of this stock after 30 years, but the lack of a proper collection system of catch data and the increasing interest in recreational fisheries raise reasons for concern.

RESUMEN El Atún aleta negra, *Thunnus atlanticus*, es capturado por una pesquería artesanal en el noreste de Brasil de septiembre a enero, pero también por pescadores recreacionales y como fauna acompañante en pesquerías industriales. La estructura de la población, relaciones morfométricas, mortalidad, reproducción y dinámica pesquera fueron estudiadas durante dos temporadas de pesca (1996 y 1997). La longitud y el peso máximos observados fueron 87 cm FL y 10 kg W_d, respectivamente. Los machos fueron mayores y predominantes (1.9:1). El tamaño al 50% de madurez fue 49.8 y 52.1 cm FL para machos y hembras, respectivamente. Esta especie usa la región para reproducción, aunque un pico de desova no fue observado. El tamaño en la primera captura (58.1 cm FL) fue más alto que el tamaño al 50% de madurez. La mortalidad total, natural, y por pesca fueron 2.34, 0.94 y 1.40 año^{-1}, respectivamente. Las relaciones longitud total-longitud furcal y longitud total-longitud estándar fueron: TL = 1.35369 + 1.0462 FL y TL = 6.37742 + 1.0544 SL, respectivamente (sexos agrupados). La relación peso-longitud estimada para ambos los sexos fue de $W_d = 0.00003\ FL^{2.8569}$. Las capturas anuales disminuyeron de 154 t año^{-1} en la década de los 70s a 33.5 t año^{-1} en la década de los 90s. Los resultados parecen indicar que no ha habido mucho cambio en la estructura de este estoque después de treinta años, pero la carencia de un sistema apropiado de la obtención de datos de captura y el interés de las industrias pesqueras recreacionales son motivo de preocupación.

INTRODUCTION

Blackfin tuna, *Thunnus atlanticus*, occur only in the western Atlantic Ocean, from Martha's Vineyard/US—40°N to Rio de Janeiro/Brazil—22°S, including the Gulf of Mexico and the Caribbean (Collette and Nauen 1983). Zavala-Camin (1991), however, recorded this species as far as 31°S (southern Brazil). Blackfin tuna reach a maximum size of 108 cm, which is much smaller than other *Thunnus* species (www.fishbase.org).

In the Caribbean region, this species supports important fisheries mainly in Venezuela, Martinique, Guadeloupe, Cuba, and Dominican Republic (FISHSTAT; www.fao.org). Off southern and northeastern Brazil, blackfin tuna are by-catch in longline fisheries targeting *Thunnus albacares*, *Thunnus obesus*, *Thunnus alalunga*, *Xiphias gladius*, and Carcarhinidae. Baía Formosa, a fishing village located in the south of Rio Grande do Norte State, is the only area in Brazil where significant aggregations of *T. atlanticus* are found close enough to the mainland to justify a handline artisanal fishery from September to January (Cruz and Paiva 1964). This fishery is important to the local economy, where almost 100% of the artisanal catch of 'albacore' is *Thunnus atlanticus*. Catches are consumed locally or sold to neighbour states: Paraíba and Pernambuco (Tartari 1966). The artisanal fishery targeting blackfin tuna in Brazil cannot be properly analyzed because national and local databases record this species as albacore ('albacora') together with 3 other species (*T. albacares*, *T. alalunga*, and *T. obesus*). Indeed, Freire

(2003), in compiling a national landing database, noted that albacore is caught by both artisanal and industrial fisheries in 14 out of the 17 Brazilian coastal states. However, blackfin tuna ('albacorinha') is recorded as being caught only after 1994 by industrial fisheries in 3 states in southern Brazil (São Paulo, Rio de Janeiro, and Santa Catarina). No catch is recorded for this species in northeastern Brazil.

Information on the biology and fishery of blackfin tuna is available primarily for the Caribbean (Carles 1974, Garcia-Coll 1987a, Carles and Valle 1989, Báez-Hidalgo and Bécquer 1994, Taquet et al. 2000, Doray et al. 2004) and for Brazil in earlier periods (Cruz and Paiva 1964, Monte 1964a, b, Cruz 1965, Nomura and Cruz 1966).

This study aims to update information on the fishery and population structure of *Thunnus atlanticus* off northeastern Brazil. In particular, we document overall catches, yield per boat per trip, length-frequency distribution, sex ratio, basic morphometric relationships, mortality rates, and length at 50% maturity and at first capture.

MATERIALS AND METHODS

A sampling program was established in Baía Formosa, Rio Grande do Norte/Brazil (6°22'S and 35°00'W; Figure 1), during September 1996–January 1997 and September 1997–January 1998, the first sampling period following more than thirty years without data collection from commercial fisheries—artisanal or industrial. This program was divided into 2 parts: size sampling, where measures of fork length (cm; FL) and gutted weight (kg; W^d = weight with no viscera or gills) of blackfin tuna *Thunnus atlanticus* were taken daily, and biological sampling, where we measured weekly total length (cm; TL), FL (cm), and W^d (kg), determined sex, and collected gonads.

All samples were taken in the 5 market places concentrated in the only landing port of the region. In both sampling programs, all individuals caught by each boat were sampled up to an overall total of 30 fishes per sampling day (some boats catch daily only 2–3 individuals). This dataset was complemented with TL and standard length (SL) data from the REVIZEE Program/NE Score (Assessment of Renewable Resources off the Brazilian Exclusive Economic Zone/Northeastern Score) for the period 1998–2000. Catch data per boat per trip for blackfin tuna were obtained from receipts available at the Baía Formosa Fishing Cooperative (1996–1998) and complemented with data from national and local statistical bulletins (CEPENE, 2000; Freire, 2003).

Frequency distributions of FL were calculated for males and females. TL-FL and W^d-FL relationships were estimated for males and females separately, with a log-transformation of W^d and FL for the latter. A SL-TL relationship was calculated for males and females combined, as sex information was not available for specimens with recorded SL.

The total instantaneous mortality rate was estimated based on the catch-curve for FL converted to age using von Bertalanffy growth parameters for blackfin tuna estimated using the routine ELEFAN I—Electronic Length-Frequency Analysis available in FISAT II—FAO-ICLARM Stock Assessment Tools (http://www.fao.org/fi/statist/fisoft/fisat/index.htm; Gayanilo and Pauly, 1997). This routine identified the growth curve that best fitted the set of length-frequency data for blackfin tuna obtained from the size sampling previously described. The natural mortality rate (M) was estimated based on the following simplified equation:

$$M = K^{0.6543} \cdot L_{\infty}^{-0.279} \cdot T_c^{0.463}$$

where: L_∞ = asymptotic length (TL; cm), K = curvature parameter of the von Bertalanffy growth curve (year^{-1}), and Tc = mean water temperature (°C) (Pauly 1980). A mean sea-surface temperature of 27.2 °C was estimated for the fishing seasons of 1996 and 1997, based on the data available from the International Comprehensive Ocean-Atmosphere Data Set—ICOADS (http://dss.ucar.edu/pub/coads/). The mean size at first capture was estimated by fitting a logistic curve to the ascending limb of the length-converted catch curve and defining the size at which 50% of the individuals are caught (L_{50}).

Maturity stages were defined macroscopically using the following scale: 1 = immature; 2 = resting; 3 = active; 4 = ripe (actual spawning condition); and 5 = spent (Jolley 1977). The weight of the gonads was measured (0.001 g) and the gonadosomatic index (GSI) was calculated for females and males as: GSI = (W_g x 100)/W_d, where W_g = gonadal weight (g) and W_d = gutted weight (g). The length at maturity was estimated for females and males as the length at which 50% of all individuals are mature. It is worth mentioning here that, although individuals are eviscerated on board (Nomura and Cruz 1966), this process involves removal of gills and viscera through the operculum, leaving the gonads intact. Hence, it is still possible to determine the sex and reproductive condition of eviscerated fish.

Length-frequency distributions for males and females were compared using a Chi-square test. Sex ratios were tested against the null hypothesis of 1:1 for each month using a Chi-square test. Length-weight and length-length relationships for males and females were compared using a t-statistic to test for both slope and intercept (Zar, 1984).

Figure 1. Location of sampling areas in northeastern Brazil. The black circle corresponds to Baía Formosa (6°22'S and 35°00'W), and the gray circles are areas where samples were collected through the REVIZEE Program/Score NE (MA = Maranhão, PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco, AL = Alagoas, SE = Sergipe, BA = Bahia). RJ = Rio de Janeiro, SP = São Paulo, SC = Santa Catarina. In the bottom-right are the countries with the highest catches of blackfin tuna in the Caribbean.

All statistical tests were performed with a significance level of 0.05.

RESULTS

From 1993 to 2001, blackfin tuna catches from the artisanal fleet operating in Baía Formosa ranged from 16.8 to 48.6 tonnes, with an annual mean of 33.5 tonnes. This estimate was obtained considering that 100% of ‘albacore’ catches in that region are actually blackfin tuna. The mean catch of blackfin tuna per boat per fishing trip was 35.3 kg for 1996–1997, with an increasing trend towards the end of the fishing season when the yield reached 50.7 kg. Length-frequency distributions for males and females were statistically different (^{2} = 71.6; DF = 23; $P < 0.0001$), with males reaching a larger size (Figure 2).

Analysis of monthly length-frequency distributions indicates that larger individuals reach the region in September and are followed later by a second mode of smaller individuals (Figure 3). The smallest observed individual was 23 cm FL and the smallest observed weight was 0.8 kg W_d (Table 1). The maximum length and weight

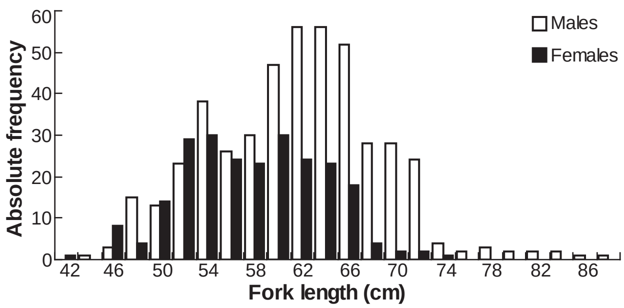

Figure 2. Length-frequency distribution for *Thunnus atlanticus* off Baía Formosa, northeastern Brazil (1996–1998). n_{males} = 458; $n_{females}$ = 237.

observed were 87 cm FL, and 10 kg W_d, respectively. Males predominated in a ratio of 1.9:1 (Table 2). Although this proportion varied during the fishing season, males were always predominant as indicated by the chi-square test, with the exception of the sample collected in January 1997. In this sample, the sex ratio was not significantly different from 1:1.

The relationships between TL and FL for females and males were not statistically different (t_{slope} = 1.70, DF = 336, and P = 0.090; $t_{intercept}$ = 1.68, DF = 337, and P = 0.094). The resulting relationship obtained for both sexes combined was: TL = 1.35369 + 1.0462 FL (Table 3). The relationship between TL and SL estimated for the sexes combined was: TL = 6.37742 + 1.0544 SL (Table 3). The relationships between W_d and FL for males and females were statistically different, with males heavier at size (Table 3; t_{slope} = 2.16, DF = 613, and P = 0.031; $t_{intercept}$ = 2.24, DF = 614, and P = 0.025). The weight-length relationship for unsexed individuals from our sampling area is: $W_d = 0.00003\ FL^{2.8569}$ (r^2 = 0.92, n = 617, P < 0.0001).

The von Bertalanffy growth curve parameters estimated based on the length-frequency distribution was: L_{∞} = 92 cm (FL), K = 0.65 year^{-1}, t_o = 0 years. The total instantaneous mortality rate (Z) estimated was 2.34 year^{-1} (Confidence interval (CI) = [1.92;2.77]; Figure 4). The natural mortality rate calculated was 0.94 year^{-1}, which implies a fishing mortality of 1.40 year^{-1} and an exploitation rate of 59.7%. The average length at first capture was 58.1 cm FL (sexes grouped; Figure 5).

The length at 50% maturity was greater for males (52.1 cm FL) than for females (49.8 cm FL) (Figure 6). The gonadosomatic index (GSI) for females did not show a clear pattern between years (Figure 7). For males, highest values of GSI were observed in December in both years. Macroscopic identification of maturity stages for females indicates that this species uses the area for reproduction, with active individuals observed as early as September or October (Figure 8). One month later running ripe individuals were observed, with some inter-annual variation.

DISCUSSION

Blackfin tuna catches from Baía Formosa were much lower in 2001 (48.6 tonnes) than in 1969–1977 (52 to 296 tonnes, with an average of 154 tonnes year^{-1}; Vasconcelos and Conolly 1980). Current catches are also lower than catches from industrial fisheries off southeastern Brazil (annual average of 172 tonnes year^{-1} for 1995–2000; Freire 2003). However, the social importance of the artisanal fishery is higher, as the local community largely depends on this fishery.

The mean yield per boat per fishing trip in 1963 was 34.9 kg (Cruz and Paiva 1964b). The yield increased to 39.3 kg in 1977 (68 boats, Vasconcelos and Conolly 1980) but decreased to 38.5 kg in 1996 (this study). These differences cannot be attributed to changes in gear selectivity; 80–140 cm long handline has been used for the last 40 years with a no. 15 hook attached to the end of the line (Vasconcelos and Conolly 1980; João C. Neto, Baía Formosa Fisher's Association, pers. com.). The only change observed during this period was the introduction of motorized boats in 1967–1968, which could account for the yield per trip being higher in the 1970s than in the early 1960s. Although these boats operate in the same fishing ground as sailboats, 12 to 16 miles from the coast (Vasconcelos and Conolly 1980), their fishing trips are longer (3–5 days versus 1 day for sailboats) and their crew is larger (4 fishers versus 3) (João C. Neto, pers. com.), thus producing higher yield per trip.

Total blackfin tuna mortality decreased from 3.16 year^{-1} in 1965 (based on Nomura and Cruz 1966) to 2.66 year^{-1} in 1977 (based on Vasconcelos and Conolly 1980) and declined again to 2.34 year^{-1} in 1996, even though the latter twoare not statistically different. More effort should be put into the collection of catch and effort data for this fishery since fishing mortality is estimated at 1.40 year^{-1}, with an exploitation rate of about 60%, which may not be sustainable. On the other hand, a length at first capture greater than the length at 50% maturity may contribute to the future sustainability of this fishery. Although the natural mortality obtained in this study is similar to those for other *Thunnus* species, there could be a size-dependence as pointed out by Hampton (2000) for *T. albacares* and *T. obesus*.

Blackfin tuna use the Baía Formosa area for reproduction, although we could not define a distinct reproductive peak using GSI or macroscopically-defined maturity

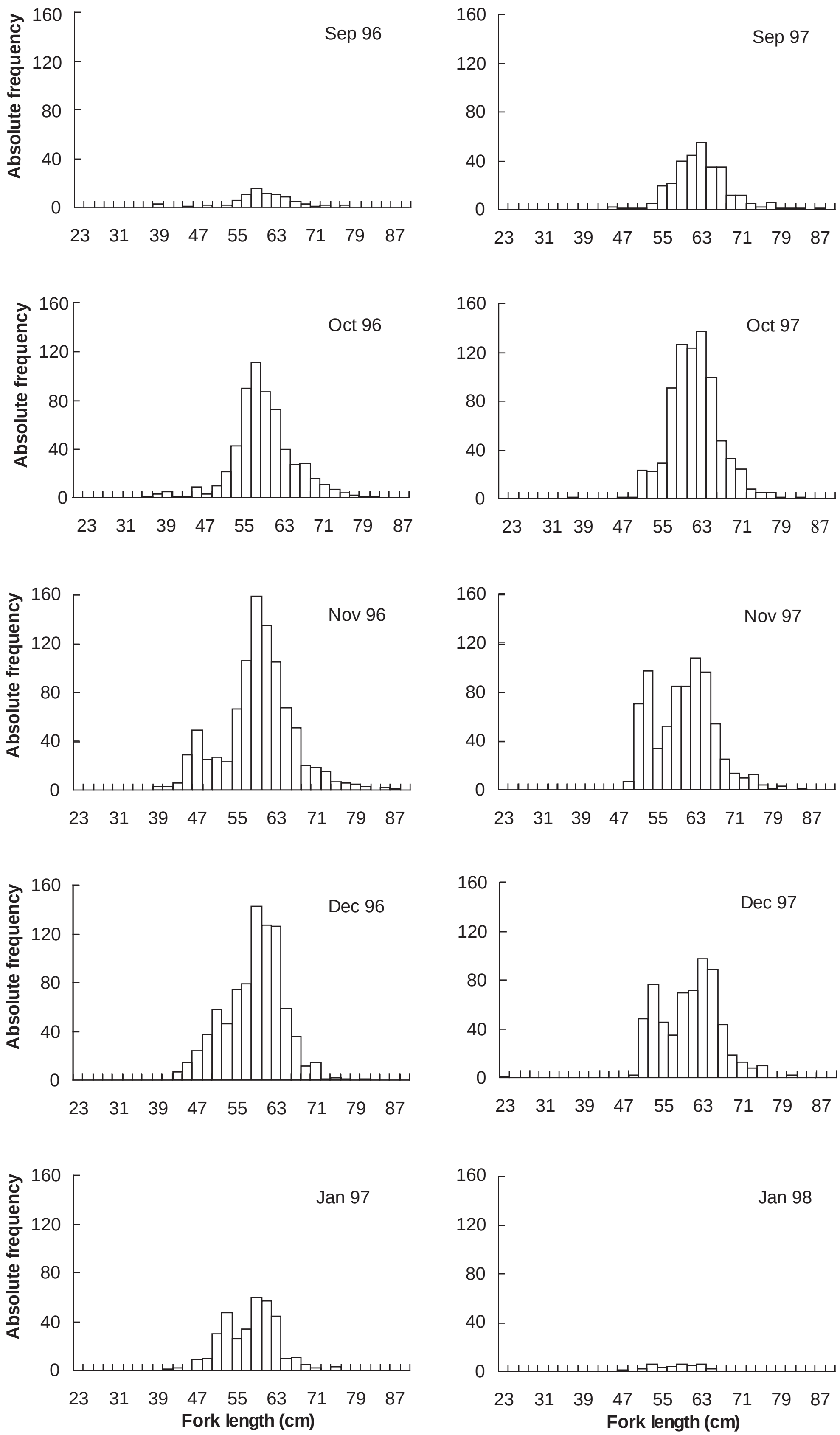

Figure 3. Monthly length-frequency distribution for *Thunnus atlanticus* off Baia Formosa (1996–1998; both sexes combined; *n* = 5315).

TABLE 1

Minimum, mean, and maximum size of *Thunnus atlanticus* off Baía Formosa sampled from September 1996-January 1998. TL = total length (cm), FL = fork length (cm), W_d = gutted weight (kg), SD = standard deviation, N = sample size.

	Unsexed			Females			Males		
	TL	FL	W_d	TL	FL	W_d	TL	FL	W_d
Minimum	50.0	23.0	0.8	50.0	39.5	1.5	53.0	43.0	1.5
Mean	63.8	59.4	3.3	61.2	56.1	2.7	65.2	60.2	3.4
Maximum	90.5	87.0	10.0	74.5	72.5	5.5	90.5	86.0	9.5
SD	6.9	6.2	1.2	5.9	5.9	0.8	7.0	7.3	1.2
N	357	5316	5209	110	237	110	230	457	230

TABLE 2

Number of males and females and sex ratio of *Thunnus atlanticus* caught off Baía Formosa by month. Jan 1998 was not included as there was no biological sampling. *Statistically significant at = 0.05.

Month	Males	Females	Sex ratio	Chi-square (^{2})	p
Oct 1996	30	15	2.0:1	5.0*	0.0253
Nov 1996	94	53	1.8:1	11.4*	0.0007
Dec 1996	67	31	2.2:1	13.2*	0.0003
Jan 1997	26	20	1.3:1	0.8	0.3771
Sep 1997	33	16	2.1:1	5.9*	0.0151
Oct 1997	104	47	2.2:1	21.5*	< 0.0001
Nov 1997	80	44	1.8:1	10.4*	0.0012
Dec 1997	24	11	2.2:1	4.8*	0.0280
Total	458	237	1.9:1	70.3*	< 0.0001

TABLE 3

Length-length and weight-length relationships for blackfin tuna *Thunnus atlanticus* off northeastern Brazil. TL = total length (cm); FL = fork length (cm); SL = standard length (cm); W_d = gutted weight (kg); N = sample size; r^2 = coefficient of determination; p = probability. * Linear relationship: $Y = a + bX$; ** Power relationship: $Y = aX^b$.

Unknown	Known	a	b	Sex	N	r^2	p
TL*	FL	0.21206	1.0678	Females	110	0.98	< 0.0001
TL*	FL	1.48854	1.0433	Males	230	0.99	< 0.0001
TL*	FL	1.35369	1.0462	Unsexed	340	0.99	< 0.0001
TL*	SL	6.37742	1.0544	Unsexed	93	0.90	< 0.0001
Wd**	FL	0.00004	2.7268	Females	218	0.86	< 0.0001
Wd**	FL	0.00002	2.8837	Males	399	0.94	< 0.0001
Wd**	FL	0.00003	2.8569	Unsexed	617	0.92	< 0.0001

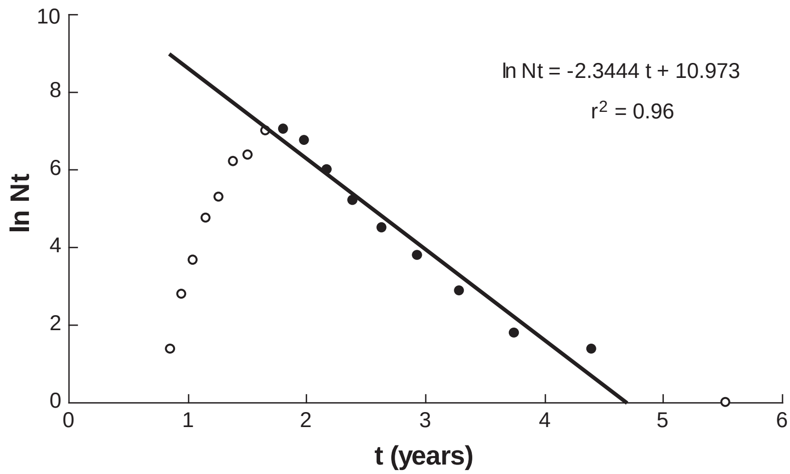

Figure 4. Length-converted catch-curve for *Thunnus atlanticus* off Baía Formosa (1996–1998; both sexes combined). Confidence interval (CI) for total instantaneous mortality (Z) = [1.92; 2.77].

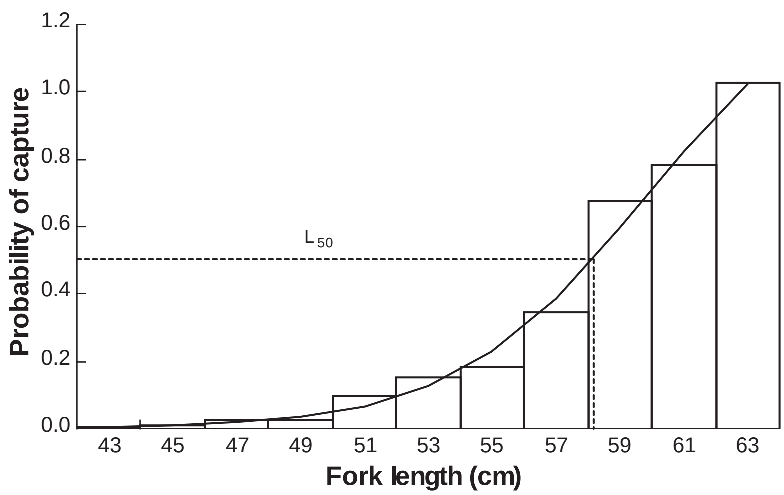

Figure 5. Probability of capture by handline for *Thunnus atlanticus* off Baía Formosa (1996–1997; both sexes combined; L_{50} = 58.1 cm FL).

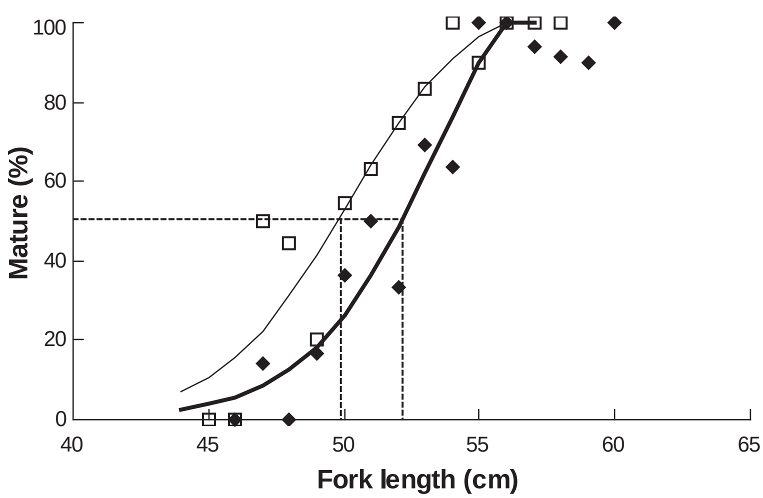

Figure 6. Sexual maturity for females (open squares) and males (solid diamonds) of *Thunnus atlanticus* off Baía Formosa (1996–1998; $n_{females}$ = 223; n_{males} = 432). Dashed lines represent length at 50% maturity (49.8 and 52.1 cm FL for females and males, respectively).

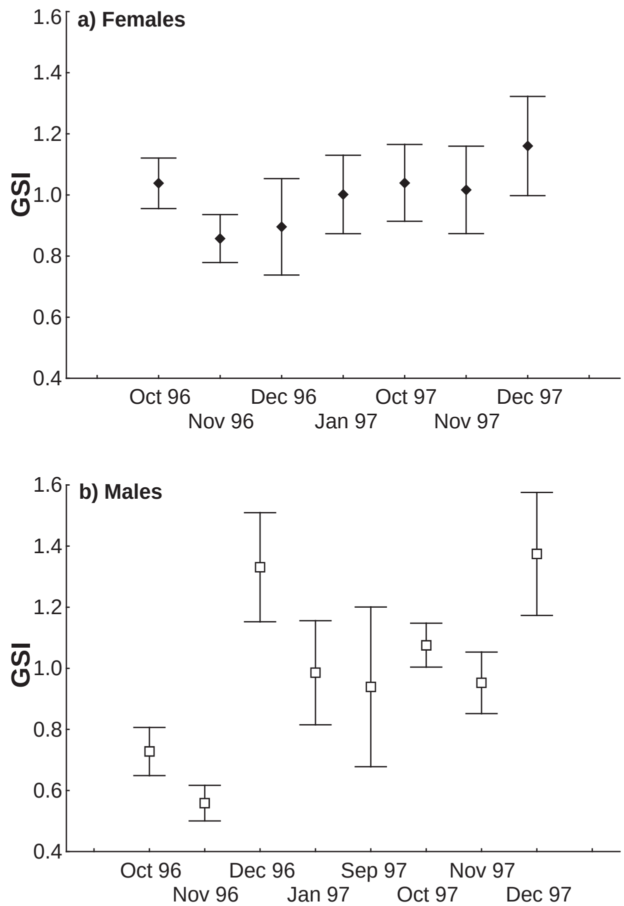

Figure 7. Variation of the mean gonadosomatic index (GSI) for females (a) and males (b) of *Thunnus atlanticus* off Baía Formosa (1996–1997; $n_{\mathbf{females}}$ = 177; $n_{\mathbf{males}}$ = 293). Whiskers represent mean ± standard error.

stages. In December, GSI for males was higher than for females, which is not common for tunas, but was also found in *T. obesus* in the Indian Ocean (Nootmorn 2004). The lack of such a peak of reproduction may be due to the pattern of immigration of this species to this region, with large individuals arriving first, followed by smaller individuals, and/or to its multiple spawning feature, commonly observed in tunas (Schaefer 2001). This author points out that sea-surface temperatures (SST) higher than 24 °C are associated with spawning activity for all tuna species. Indeed, local SST was in excess of 26 °C during the whole sampling period (http://dss.ucar.edu/pub/coads/), which would reinforce the hypothesis of continuous spawning activity. However, there is no information on the occurrence of larvae of *T. atlanticus* in this region, probably due to identification difficulties for *Thunnus* larvae (Richards et al. 1990). In contrast to Brazil, spawning occurs year round in Cuba, with a clear peak in June–September (Valle-Gomez 1992). In southeastern US, spawning occurs from April to November (Idyll and de Sylva 1963).

Males are larger than females, as also observed for nearly all tuna species (Schaefer, 2001), and mature at a slightly larger size. Although a larger maturity size for males is not common in scombrids, length at 50% maturity for *Katsuwonus pelamis* in both Atlantic and Indian oceans was reported to be larger for males than for females (Cayré and Farrugio 1986, Stéquert and Ramcharrun 1996). A detailed histological study would be able to test if this difference is real or possibly attributed to the misclassification of maturity stages using macroscopic analysis.

Monte (1964b) pointed out that sexual maturation for both sexes of blackfin tuna occurring in northeastern Brazil in the early 1960s begins at 50 cm FL, with a higher frequency of ripe females at 56–65 cm FL. These values are higher than the size at 50% maturity estimated in this study. Such reduction in maturity size could result in shorter reproductive life span and reduced fecundity, even though a compensatory increase in mean individual fecundity has been observed for some species (Jennings et al. 2001). There are no conclusive data on the length at 50% maturity for the Caribbean, except for an indication of sexual differentiation occurring in individuals 39 cm long in Cuba (Carles 1971) and an indication that individuals smaller than 41 cm are immature in Martinique (Taquet et al. 2000).

Males were predominant off Baía Formosa in 1996 (1.9:1) as they were in the 1960s (1.6:1; Monte 1964b), with some variation during the fishing season. A predominance of males was also observed off Cuba (1.6:1, Garcia-Coll 1987b) and off Miami (2:1, Idyll and de Sylva 1963). Although the overall sex ratio for most tuna species is 1:1, some concentration of males occur when females are reproductively active (Schaefer 2001), as observed here.

In addition to the apparent reduction in the length at 50% maturity for females, their mean size also decreased by about 1.5 cm FL in 34 years. However, smaller and bigger individuals were sampled in 1996–1997 (23–87 cm FL; this study) than in 1963–64 (51–80 cm FL, Monte 1964b), 1965–1966 (45–79 cm FL, Nomura and Cruz 1966) and 1977 (36.5–81.5 cm FL, Vasconcelos and Conolly 1980). These observed changes cannot be attributed to gear selectivity, as gear has remained the same during this period. Instead, they indicate actual changes in the population and represent signs of intense exploitation, as observed, for example, for *Micropogonias undulatus* (Atlantic croaker) in the northwestern Atlantic (Diamond et al. 1999). However, because *T. atlanticus* is a migratory species, these effects are likely to be a result of local

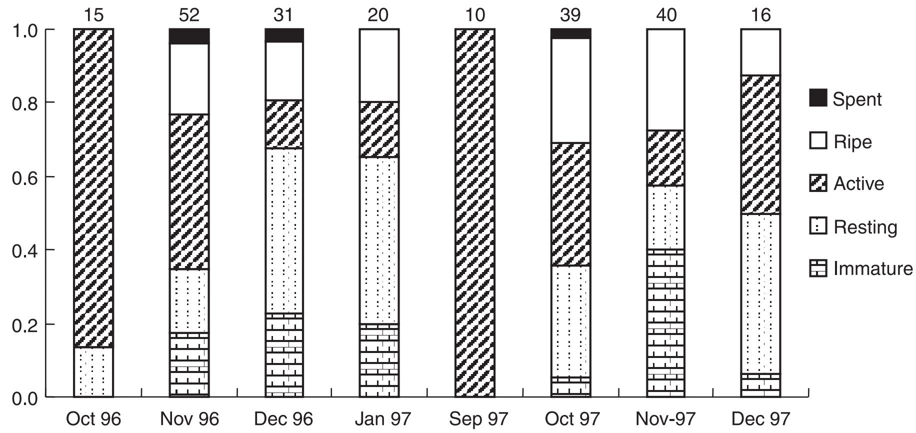

Figure 8. Proportion of the stages of maturity for females of *Thunnus atlanticus* off Baía Formosa (1996–1997). Sample sizes are presented on the top of each column.

exploitation combined with that from other areas in the distribution range of the stock.

Some changes have been noted in the population structure, in catches, and in yield of blackfin tuna. Although these changes are not large enough to cause great concern, they should be seen as a warning sign by the national agencies in charge of fisheries management (SEAP—Special Secretary of Aquaculture and Fisheries and IBAMA—Brazilian Institute for the Environment and Renewable Resources) and should promote improved data collection for artisanal fisheries targeting small tunas. The importance of blackfin tuna in the food web of large pelagic fish is not well understood, as it is often difficult to identify species or even genera of scombrids found in the guts of billfish, swordfish, dolphinfish, and sharks (Vaske-Júnior 2000). There is also an increasing demand for oceanic recreational fisheries in the region (Freire in press), which could ultimately put more pressure on this resource. Thus, it is imperative that our understanding of blackfin tuna be improved sooner rather than later.

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