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EVIDENCE OF BLUE MARLIN (*MAKAIRA NIGRICANS*) SPAWNING IN BERMUDA WATERS AND ELEVATED MERCURY LEVELS IN LARGE SPECIMENS

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ABSTRACT

The gonads of 11 adult female blue marlin (*Makaira nigricans* Lacépède, 1803) caught mostly in July in Bermuda waters (2002–2005), and ranging in weight from 242–465 kg, were evaluated histologically for reproductive status. The gonadosomatic index (*GSI*) of these specimens ranged from 0.70%–6.22%; specimens with a *GSI* ≥ 3 were reproductively active. Based on gonad histology, 70% of the females caught in July were actively spawning or in spawning condition, with post-ovulatory follicles (POFs) or in final stages of oocyte maturation. These observations confirm that active spawning occurs in Bermuda waters in July and significantly extends the known northern spawning range of blue marlin in the western Atlantic Ocean. In addition, our largest specimen (465 kg) examined histologically was in spawning condition. This appears to be the first reproductively active specimen of this size ever reported. For the first time, a juvenile blue marlin (256 mm lower jaw fork length) was collected at Bermuda's northerly latitude (32°N). The estimated age of this specimen (42 d), obtained by counting daily growth increments on the sagitta, produced an estimated birth date in mid-July. White muscle tissue samples from 13 blue marlin (50–545 kg) specimens from the western North Atlantic (four from Bermuda), were analyzed for total mercury (THg) and had values from 1.77–12.7 ppm. These values are amongst the highest THg concentrations reported in any teleost. The high reproductive potential of the largest females, as well as their questionable food value due to THg contamination, suggests that consideration be given to reducing fishing mortality.

Blue marlin (*Makaira nigricans* Lacépède, 1803) are widely distributed in the tropical and temperate waters of the Pacific, Indian, and Atlantic Oceans. In the Atlantic, the latitudinal range is about 45°N–35°S (Rivas, 1974) and seasonal sea temperatures likely play a major role in their spatial distribution (ICCAT, 1998; Humston et al., 2000; Olson, 2002). In the North Atlantic, the distribution of blue marlin expands in a northerly direction during the warmer months and constricts towards the equator during colder months (ICCAT, 1998). Adult blue marlin are present in Bermuda waters from May to October (Luckhurst, 1994; Luckhurst, 1998) and peak abundance appears to be in July and August when surface water temperatures are 27–28 °C (www.bbsr.edu).

The central and northern Caribbean Sea and Bahamas are well known for occasional catches of gravid adult blue marlin (Erdman, 1968; de Sylva and Breder, 1997; ICCAT, 1998). Evidence for blue marlin spawning in this region has been inferred from the following: tracking reproductive maturation in adults (Erdman, 1968; Yoe, 1978; de Sylva and Breder, 1997), observations of gravid adults (Erdman, 1968), and the presence of larvae and post-larvae (de Sylva and Breder, 1997; Serafy et al., 2003a,b). However, at the more northerly latitude of South Carolina (32°–33°N), there is no evidence of active spawning as the blue marlin population is composed of migratory mature males and post-spawn females (Cyr, 1987).

The first indication that blue marlin could be spawning as far north as Bermuda (about 32°N) came in 1994, when a post-larval (juvenile) blue marlin was collected in Bermuda waters (Luckhurst, unpubl. data). Such specimens are rarely reported, presumably due, in part, to relatively low abundances (Richards, 1984), and the inherent difficulties of sampling small, highly mobile post-larval life stages. An adult gravid female blue marlin was first observed from Bermuda waters in July 2002, followed by a series of observations of gravid females in July in subsequent years (Luckhurst, unpubl. data). These observations included some large specimens caught at an annual blue marlin tournament.

Given that the longevity of blue marlin specimens over 454 kg (1000 lbs) is estimated to be 30+ yrs (Hill et al., 1989), and their position as top predators in the pelagic trophic web (Kitchell et al., 2004), there is considerable potential for large blue marlin to accumulate relatively high levels of mercury in their tissues. Adams et al. (2004) analyzed muscle tissues of 108 species of teleosts, sharks, and rays from off the Florida coast for total mercury (THg). They found varying levels of THg in all species, but blue marlin appeared to have some of the highest levels of THg of the species examined. The sampling of a number of large blue marlin (including two specimens over 454 kg) in Bermuda over the past 4 yrs has provided the opportunity to analyze their white muscle tissue for mercury levels.

Here, we examine the reproductive condition of blue marlin landed in an annual marlin tournament to assess their reproductive status off Bermuda, which is beyond the documented northern limit of spawning within the North Atlantic. In addition, we document the first occurrence of a juvenile Atlantic blue marlin in Bermuda waters, provide an estimate of its age-at-capture using the daily otolith increment method, and back-calculate its hatch date based on the date and size/estimated age-at-capture. Lastly, we provide an estimate of THg found in the tissues of larger blue marlin caught off Bermuda and compare these to blue marlin samples from other areas of the western North Atlantic. We then relate these preliminary data to existing U.S. public health standards for mercury consumption.

Materials and Methods

Gonadal Analysis.—The gonads of 11 female blue marlin were collected for evaluation of reproductive status from July 2002 to July 2005. All specimens but one (August 26, 2002) were sampled during the Bermuda Big Game Classic (BBGC) Fishing Tournament, which has been held in mid-July each year since its inception in 2001. Due to the tournament minimum weight limit of 227 kg (500 lbs), all specimens reported here exceed this weight. Whole gonads were removed from the specimens after weighing at dockside and immediately placed on ice for short-term preservation. Each pair of gonads was weighed to the nearest 227g (0.5 lb) using an electronic scale. In three of the specimens, the two lobes of the ovary were weighed separately.

A gonadosomatic index (*GSI*) was calculated using the formula: $GSI = [GW/(TW - GW)] \times 100$ where GW = gonad weight and TW = total weight for each specimen (DeVlaming et al., 1982). These *GSI* values were used to help assess reproductive status and to allow comparisons between specimens of different weights. For both histological and whole-oocyte examination, a transverse ovary section from each specimen was fixed in 10% formalin and later rinsed and transferred to 70% ethanol. Two facilities and, thus, two methods for histological preparation were utilized. Samples from 2002 were embedded in glycol methacrylate, transversely sectioned (5 μm), stained with periodic acid-Schiff's hematoxylin, and counterstained with metanil yellow (Quintero-Hunter et al., 1991). Samples collected in 2004 and

2005 were embedded with paraffin and 5-µm sections were stained with hematoxylin and eosin. Inferred spawning activity follows Hunter et al. (1992), and is based on the presence of postovulatory follicles, indicating a recent spawning event, and the developmental status of the oocytes themselves, which yields information on future spawning (e.g., Wallace and Selman, 1981; Hunter and Macewicz, 1985). Gonad sub-samples for whole-oocyte examination were placed in glass sample dishes and were viewed with a dissecting microscope under 6–10× magnification.

Juvenile Blue Marlin.—Our juvenile blue marlin was captured in surface waters at night on September 2, 1994, using a dip-net. The sample was collected on Challenger Bank (32°05 N, 65°01 W), about 20 km southwest of the Bermuda reef platform. Water depth at the collection site was 60 m. The specimen was maintained on ice at sea before being frozen for short-term preservation. In the laboratory, the specimen was weighed to the nearest 0.1 g and measured for lower jaw fork length (*LJFL*) to the nearest mm. Using a dissecting microscope and fine diameter surgical needles, the sagittal and lapillar otoliths were removed from the cranium. They were cleaned and prepared for microstructural examination (video microscope with polarized light illumination) following the methods described by Brothers (1987) and Prince et al. (1991). The otoliths did not require sectioning and were found to be thin, relatively transparent, slightly decalcified, and too brittle to permit further manipulation. Structural criteria (spacing and optical density) were used to distinguish presumptive daily growth increments from sub-daily increments. The hatch date was determined based on an estimate of age at the date of collection using protocols and methods of Prince et al. (1991).

Mercury Analysis.—Samples of white muscle tissue (~10–15 g) were collected opportunistically in Bermuda and at various locations in the western North Atlantic during the course of gonad sampling. Tissue samples were collected at dockside and stored on ice prior to freezing and mercury analysis. For continuity, all tissue samples were removed from the left shoulder, above the lateral line system. To minimize sample contamination, no contact was allowed between the sample and the dermal layer, scales or other surrounding tissues during removal (Adams and Onorato, 2005). For analysis, final preparation of the samples included trimming the outer most layers with a new sterile scalpel (for each sample) and transferring them into a sterile polyethylene vial, with minimal head-space to limit water loss. Samples were stored at –20 °C, then analyzed for total mercury (THg) by Frontier Geosciences Inc., Seattle [www.frontiergeosciences.com]. Each sample aliquot was run with stannous chloride reduction, dual gold amalgamation, and cold vapor atomic fluorescence. The analysis was based on the EPA 1631E method, Frontier SOP FGS-069, which is for cold vapor atomic fluorescence spectrometry (CV-AFS). Linear and exponential regressions were run to describe the relationship between fish weight and THg level in samples from Bermuda, as well as other areas of the western North Atlantic.

Results

Gonad Analysis.—The gonads from a total of 11 female blue marlin, ranging in weight from 242–465 kg (533–1023 lbs) were evaluated for reproductive status (Table 1). Based on the *GSI* values and the macroscopic evaluation of the gonads, it appeared that seven of the 10 specimens landed in July were reproductively active, with the ovaries of one specimen containing hydrated eggs, suggesting imminent spawning.

The largest *GSI* value (6.22%) was recorded from a specimen which was 256 kg (570 lbs), while the largest specimen 465 kg (1023 lbs) had a *GSI* of 3.91% (Table 1). Three July specimens of 283–315 kg (624–694 lbs) had a *GSI* of < 1%. The one specimen in August appeared reproductively inactive and also had the lowest *GSI* value (0.70 %) of the 11 specimens sampled. It appears from these limited data that all specimens with a *GSI* of > 3 are reproductively active (Fig. 1).

Table 1. Reproductive status of 11 female blue marlin from Bermuda (collected via tournaments with 227 kg minimum). *GSI* = gonadosomatic index.

Specimen	Collection date	Specimen weight kg (lbs)	Ovary weight kg (lbs)	*GSI*	Ovary histology characteristics and classification	Active, spawning: Recently spawned and spawning imminent
1	July 12, 2002	282.3 (621)	8.2 (18)	2.99	Early final oocyte maturation, postovulatory follicles present	Active, spawning: Spawning imminent; recent spawning is uncertain due to ovulation
2	July 13, 2002	259.1 (570)	15.2* (33.4)	6.22	Ovulated eggs present (final oocyte maturation complete), postovulatory follicles present	Active, nonspawning: In spawning condition, but no spawn in past and future ca. 24 hrs.
3	July 14, 2002	252.7 (556)	3.5(7.8)	1.42	No final oocyte maturation or postovulatory follicles, vitellogenic (advanced yolked) oocytes present	Active, spawning: Recently spawned and spawning imminent
4	July 18, 2002	327.7 (721)	9.8 (21.6)	3.09	Early final oocyte maturation, postovulatory follicles present	Inactive
5	Aug 26, 2002	411.8 (906)	2.9 (6.3)	0.70	No vitellogenic oocytes, oocyte atresia occurring	Active, spawning: Spawning imminent
6	July 10, 2004	242.3 (533)	11.8 (26)	5.13	Early final oocyte maturation	Inactive
7	July 10, 2004	315.5 (694)	2.5 (5.4)	0.78	No vitellogenic oocytes, oocyte atresia occurring	Active, nonspawning: In spawning condition, but no spawn in past and future ca. 24 hrs.
8	July 14, 2005	465.0 (1,023)	17.5 (38.5)	3.91	No evidence of final oocyte maturation or postovulatory follicles, vitellogenic (advanced yolked) oocytes present	Inactive
9	July 15, 2005	290.9 (640)	2.5 (5.5)	0.87	No vitellogenic oocytes, oocyte atresia occurring	Inactive
10	July 15, 2005	283.6 (624)	2.0 (4.4)	0.71	No vitellogenic oocytes, oocyte atresia occurring	Active, spawning: Spawning imminent
11	July 16, 2005	258.6 (569)	7.5 (16.5)	2.99	Early final oocyte maturation	

* Minimum estimate—some eggs released on deck of fishing vessel before ovaries weighed

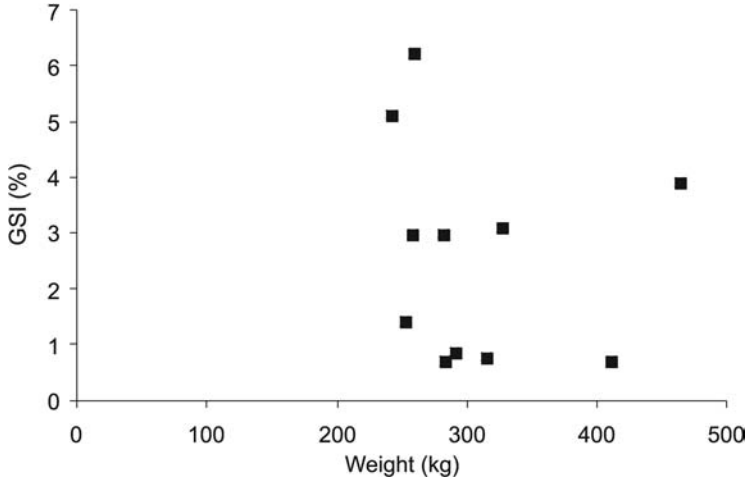

Figure 1. Gonadosomatic indices (*GSI*) and weights of 11 blue marlin caught off Bermuda (Table 1). All specimens with a *GSI* of > 3 were in spawning condition.

Gonad Histology.—Seven out of 10 blue marlin caught in July were actively spawning or in spawning condition (Table 1). Two of these females (specimens 1 and 4 Table 1; Fig. 2) showed evidence of recent and imminent spawning due to the presence of postovulatory follicles (POF) and oocytes undergoing the early stages of final oocyte maturation (FOM), specifically that of nuclear migration and yolk coalescence. The three other actively spawning females indicated spawning was imminent prior to capture due to the display of early FOM (specimens 6 and 11, Table 1) or possessing ovulated eggs ready to be spawned (specimen 2, Table 1; Fig. 2). In this latter case, as the process of ovulation includes the shedding of the follicle and the time series of follicle degradation has not been evaluated for blue marlin, it is not certain whether the postovulatory follicles present are only those of the spawning event that is about to occur, or includes those of a previous spawn. In addition, two specimens were classified as active but nonspawning, as neither possessed POFs or oocytes within the stages of final oocyte maturation; however, the presence of vitellogenic (advanced yolked) oocytes indicated that spawning could be initiated at any time. One of these two specimens was the largest female examined (specimen 8, Table 1) at 465 kg, with ovaries measuring 8.5 kg (75 cm long) and 9.0 kg (88 cm long). All four specimens classified as inactive did not have vitellogenic oocytes and oocyte atresia was occurring.

Juvenile Specimen.—The juvenile specimen, which weighed 88.1 g and was 256 mm *LJFL* (or 285 mm total length TL), clearly illustrates the unique reticulated lateral line system found in small juvenile blue marlin (Fig. 3). The estimated age of 42 d was obtained by counting daily growth increments on the sagitta (Fig. 4) and produced an estimated birth date of July 22, 1994.

Fish Weight and Mercury Levels.—White muscle tissue samples from a total of 13 specimens from the western North Atlantic (Table 2) were analyzed for total mercury concentrations. Four of these specimens were from Bermuda ranging in weight from 240–545 kg (528–1199 lbs). The range in THg content in these specimens was from 0.7–12.2 ppm (Table 2). The remaining nine specimens of 50–287 kg (110–632 lbs) had THg concentrations of 1.77–12.7 ppm (Table 2). A linear regression of the pooled data indicated no significant correlation ($r^2 = 0.227$, NS) between weight and THg, while lin-

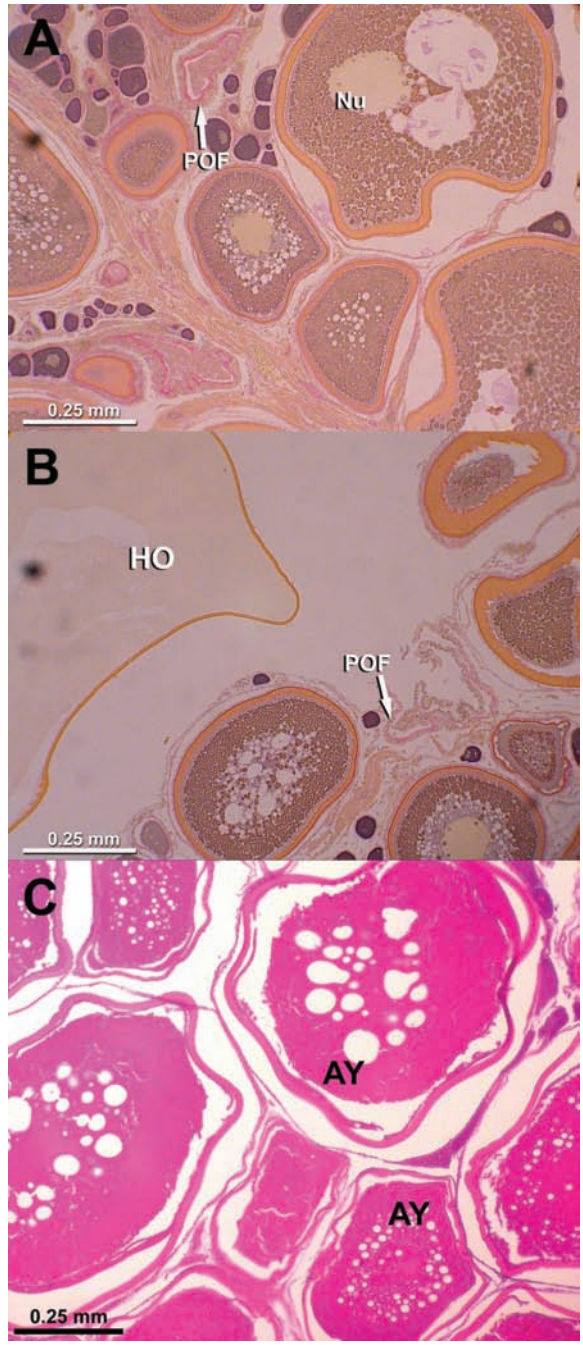

Figure 2. Histological sections of ovarian tissue from blue marlin caught off Bermuda. All references are to specimens listed in Table 1. (A) Postovulatory follicles (POF) and nuclear (Nu)-migration stage oocyte - specimen 1. (B) Hydrated oocyte (HO) and postovulatory follicle - specimen 2. POF is likely from the recently-occurred ovulation, but without knowledge of POF degeneration stages a previous spawn cannot be inferred based on the presence of POFs. (C) Vitellogenic, or advanced-yolked stage (AY), oocytes -specimen 8. Suboptimal preservation and histological preparation preclude classification beyond active spawner (i.e., whether final oocyte maturation has begun).

Figure 3. A 256 mm *LJFL* juvenile Atlantic blue marlin (*Makaira nigricans*) captured in surface waters at night on 2 September, 1994 using a dip-net at Challenger Bank, Bermuda.

ear and curvilinear regressions of the Bermuda specimens indicated high correlations, $r^2 = 0.912$, $P = 0.044$ and $r^2 = 0.962$, $P = 0.038$, respectively (Fig. 5).

Discussion

Blue marlin are ecologically and economically important fish and understanding their life history, ontogeny, population dynamics, and essential habitat are important elements required for maintaining sustainable fishery resources (Atlantic Billfish Research Plan, http://www.sefsc.noaa.gov/PDFdocs/ABRP_01_30_04.pdf, Version 1.4, 01/30.04). In the context of life history, identification of spawning areas provides insight into the sources of recruits to better understand the processes controlling recruitment, growth, and survivorship of these apex predators.

Until recently, there has been little biological sampling of blue marlin adults in Bermuda waters due to the fact that the recreational fishery has become primarily catch and release. Release rates for blue marlin were < 50% during the 1980s (Luckhurst, 2000) but then increased significantly from 1990 onward. The mean release rate of blue marlin from 1987–2001 was about 92% for recreational catches (Luckhurst, 2003). This successful conservation effort, however, has hindered the determination of seasonal and size-structured reproductive condition due to the paucity of landed specimens. The advent of the Bermuda Big Game Classic fishing tournament in 2001 presented the opportunity to sample specimens landed during the three day event, which has been held each year since its inception.

Blue Marlin Spawning in Bermuda.—The macroscopic evaluation of gonads and subsequent histological examination provided the opportunity to link *GSI* values with the reproductive state of each specimen. Despite the limited sample size, our data suggest that blue marlin with a *GSI* of about ≥ 3 are reproductively active. The two specimens with hydrated eggs present also exhibited the highest *GSI* values of 5.13 and 6.22 (specimens 2 and 6, respectively). In relation to gonad histology, the time frame for final oocyte maturation and the degeneration of postovulatory follicles in relation to spawning events is not established specifically for istiophorids. However, evidence based on other marine teleosts, including other scombroids, has shown temporal proximity to a past and future spawning event of < 24 hrs with the

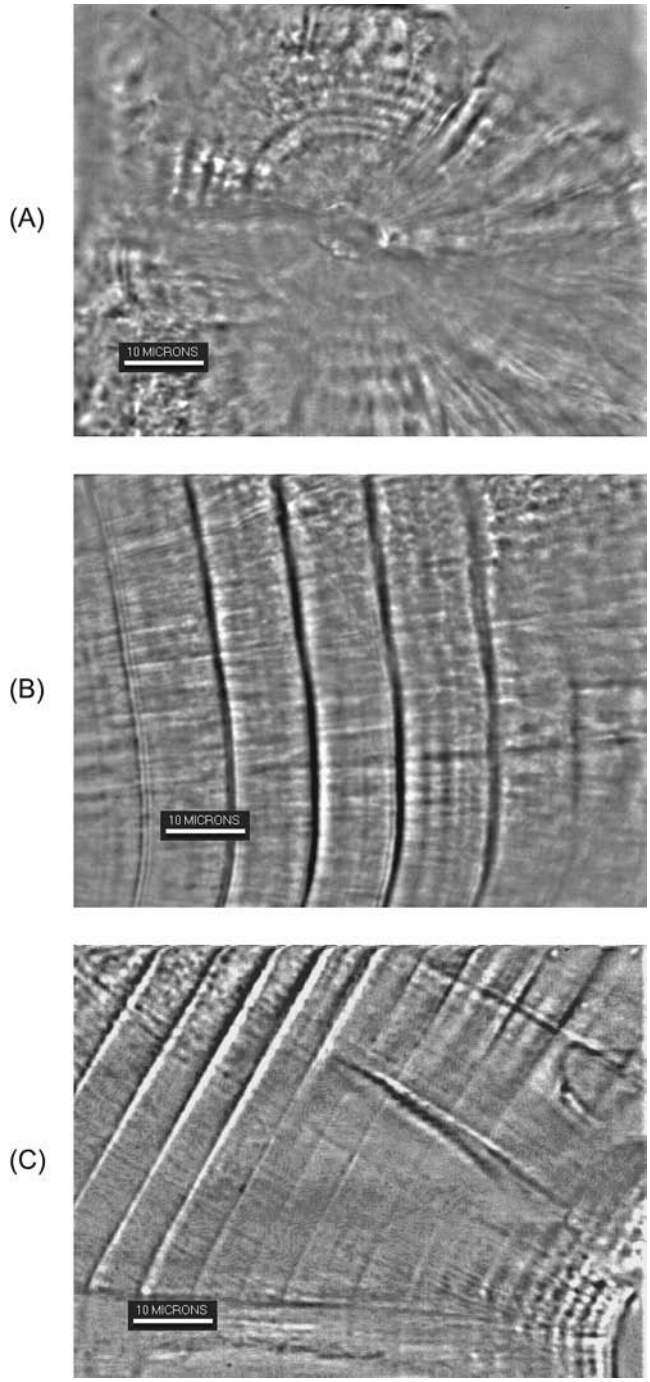

Figure 4. Enhanced digital images of a juvenile blue marlin sagitta obtained using videography and light microscopy. These images illustrate: (A) the region around the sagittal primordium and core; (B) wider "daily" increments with obvious sub-daily structures; and (C) area close to the otolith margin (extreme lower right).

Table 2. Analysis of total mercury (THg, ppm) for 13 specimens of western North Atlantic blue marlin (*Makaira nigricans*). Data are presented by latitude for geographic sampling location (north to south). Specimens are listed in ascending order by weight (wt) for Bermuda and Gulf of Mexico.

Location	THg (ppm)	Wt, kg (lbs)
Maryland	6.22	166 (367)
Bermuda	0.70	239 (528)
Bermuda	1.20	343 (757)
Bermuda	7.49	465 (1,023)
Bermuda	12.20	545 (1,199)
Bahamas	2.71	174 (383)
Gulf of Mexico	7.04	119 (262)
Gulf of Mexico	2.70	175 (386)
Gulf of Mexico	7.93	183 (404)
Gulf of Mexico	2.03	214 (473)
Gulf of Mexico	4.42	283 (624)
Gulf of Mexico	12.70	286 (632)
Caribbean	1.77	50 (110)

presence of postovulatory follicles and oocytes undergoing final oocyte maturation, respectively (e.g., Hunter and Macewicz, 1985; Hunter et al., 1986; Davis and West, 1993; Schaefer, 1996). Extending this time frame to our blue marlin specimens that displayed these features, and considering the characteristically recent postovulatory follicles seen in these fish and the warm waters (28 °C) of the region, it appears as if the waters of Bermuda serve as spawning grounds for North Atlantic blue marlin. Further supporting this conclusion is the evidence from two specimens of both recent and imminent spawning (i.e., likely occurring on consecutive days), and one specimen possessing ovulated eggs that could have been spawned at any moment.

Establishing that blue marlin are actively spawning in Bermuda waters represents a significant northern expansion of the known spawning area for blue marlin in the western North Atlantic Ocean. Confirmation of blue marlin spawning activity in close proximity to Bermuda is further suggested by the extent of movement of nine blue marlin tagged with pop-up satellite archival tags during 5 d deployments in Bermuda waters in which all specimens remained well inside Bermuda's 200 mi Exclusive Economic Zone (Graves et al., 2002). Spawning of blue marlin in July was also reported by Erdman (1968) and de Sylva and Breder (1997). Cyr (1987) reported the presence of only post-spawn females in South Carolina during the summer and suggested that spawning probably occurred earlier in the year at lower latitudes. Without adequate samples from other months, it is not possible to determine the duration of spawning in Bermuda waters.

There has been some speculation in the scientific community concerning the potential reproductive contribution of the largest members of the blue marlin population, all of which are female (Wilson et al., 1991). Given the potential age (30+ yrs) of specimens over 454 kg (1000 lbs; Hill et al., 1989), the possibility that the largest females might become reproductively senescent and no longer contribute to the reproductive output of the population remains unresolved. We believe that our largest specimen (specimen 8), provides the first confirmation of active spawning in an Atlantic blue marlin specimen > 454 kg. Based on gonad histology, this specimen was in active spawning condition. Although any size or age-related differences in spawning

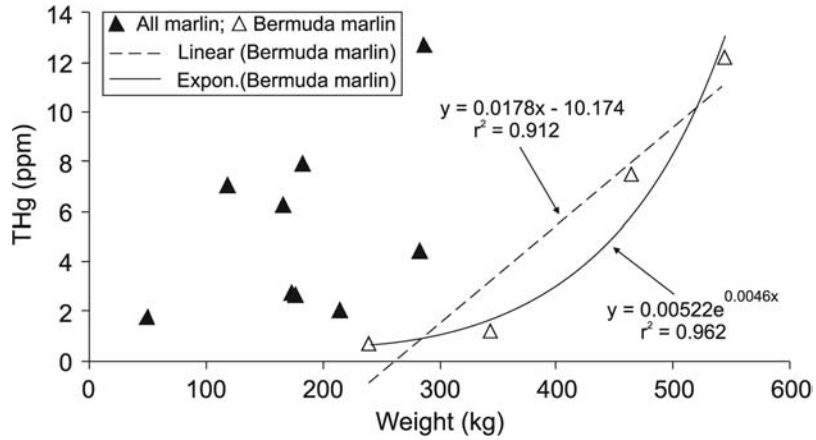

Figure 5. Relationship between total mercury (THg) in white muscle tissue and weight of blue marlin (Table 2) from the western North Atlantic (solid triangles) and Bermuda (hollow triangles). A curvilinear regression (solid line) of the Bermuda specimens (n = 4) yielded a higher correlation ($r^2 = 0.962$, $P = 0.038$) than the linear regression (dashed line, $r^2 = 0.912$, $P = 0.044$).

frequency are unknown, these large fish may potentially provide a disproportionately large reproductive contribution to the population due to their greater fecundity.

The collection of a juvenile blue marlin of the size reported here is a relatively rare event (de Sylva, 1958; Herald, 1968; Prince et al., 1991). The absence of distinctive adult characteristics in juvenile blue marlin, particularly the extended anterior portion of the dorsal fin and the prominent upper bill (snout) that are so conspicuous in adults, appears unique among species of Istiophoridae and no doubt contributed to the lack of a definitive description of post-larval blue marlin until Caldwell's (1962) report. In fact, as early as the mid-1950s, Gehringer (1956) first described an unknown juvenile istiophorid with these same features that was later confirmed to be a juvenile blue marlin. Our finding is the first documented collection of such a specimen from Bermuda waters. Our estimate of the age at capture (42 d) and hatch date (July 22, 1994) of this specimen fits well with previous estimates of age and growth, spawning periodicity, and peak spawning period (July) reported for western Atlantic blue marlin (Erdman, 1968; Prince at al., 1991; Serafy et al., 2003a,b). While it is possible that this juvenile was the result of spawning in Bermuda waters, the possibility that this juvenile was spawned at lower latitudes and was transported to Bermuda via the Gulf Stream or through significant horizontal swimming cannot be discounted.

Fish Weight and Mercury Levels.—Mercury occurs naturally in the environment, but can also be released into the air through industrial pollution. Mercury falls from the air and accumulates in streams and oceans, where it is turned into methyl mercury (MHg) in the water. Methyl mercury is thought to be harmful if consumed by humans, particularly for unborn babies and young children (Adams, 2004). Fish absorb the methyl mercury as they feed and the process of accumulation over time results in higher concentrations of MHg in fish tissues. Some species of fish and shellfish tend to concentrate MHg in their tissues at higher levels than other species, depending on the fish's diet and age (Bloom, 1992; Adams et al., 2003). Thus, levels of MHg and THg are variable (US-EPA, http://www.epa.gov/waterscience/fishadvice/advice.html). Bloom (1992) noted that the observed mean MHg proportion of THg measurements was 95%–99% for blue marlin. The highest level of THg recorded in

our study (12.7 ppm for a Gulf of Mexico specimen) is amongst the highest values recorded for blue marlin. The highest value from our Bermuda specimens was slightly lower at 12.2 ppm THg. Shomura and Craig (1975) found THg levels ranging from 0.19–7.86 ppm in blue marlin from Hawaii, while Barber and Whaling (1983) found a maximum THg level of over 15.0 ppm for blue marlin caught off the US east coast (33°–39°N). Both studies found a trend of increasing MHg with increasing size of fish. Recently, Russell (2005) reported a mean THg of 4.08 ppm for blue marlin sampled in Australia and, in common with previous studies, showed an increase in THg with an increase in fish size. The maximum value recorded in a recent survey of mercury levels in 108 Florida fish species (Adams et al., 2003) was for a great white shark (*Carcharodon carcharias*, Linnaeus, 1758) at 10 ppm. However, blue marlin had the next highest THg value at 6.8 ppm. The United States EPA and Florida Department of Health guidelines for fish consumption indicate that any specimen with a mercury level > 1.5 ppm in their muscle tissue should not be consumed in any amount (EPA, 1991; HRS, 1995).

It is difficult to assess trends with our small sample size. When all specimens were pooled, there was no significant relationship between specimen weight and THg concentration, but the correlation using only the four Bermuda specimens was very high ($r^2 = 0.96$). Although there may be significant variation in mercury levels both within and between geographic regions with respect to size, our limited sample size does not permit any conclusions and we are not able to attribute these differences to regional anthropogenic or natural factors.

From a trophic perspective, three species of tuna (yellowfin tuna, *Thunnus albacares*, Bonnaterre, 1788; blackfin tuna *T. atlanticus,* Lesson, 1831; and little tunny, *Euthynnus alletteratus*, Rafinesque, 1810) from off Florida had mean THg quantities of 0.25–1.07 ppm, with the highest levels in little tunny (3.4 ppm) (Adams, 2004). All three of these species are common in Bermuda waters and blue marlin would have the opportunity to accumulate mercury by feeding on these species.

Relevance of Our Findings.—The blue marlin stock in the Atlantic Ocean is considered overexploited (ICCAT, 2001) and the main source of fishing mortality is longline fishing effort. Blue marlin are taken primarily as by-catch in the longline fishery and are rarely a target species in commercial fisheries. However, recreational billfishing often specifically targets large blue marlin. In many countries in the western Atlantic, catch and release fishing for billfish is widely practiced and the great majority of fish are released. However, in some countries, blue marlin are still retained and marketed. In an effort to rebuild the stock, ICCAT has concluded that fishing mortality will have to be dramatically reduced (ICCAT, 2001). We suggest that it would be prudent to consider the contribution of the largest fish to the blue marlin population in the rebuilding process, given the following: (1) blue marlin > 454 kg are still capable of spawning; (2) the largest females potentially contribute proportionally more ova to the reproductive potential of the stock; (3) the contribution of the largest female blue marlin to the population gene pool is inherently beneficial relative to the resilience of the population to withstand exploitation; and (4) current regulations in the United States and Bermuda jurisdictional waters use minimum size limits to regulate blue marlin landings (Venizelos et. al., 2003), which encourages continued harvest of the largest females. In addition, the food value of this species comes into question given the very high levels of THg in muscle tissue of larger females. As pointed out by Birkeland and Dayton (2005), it is important to

protect the largest, most fecund females in a population to help maintain the reproductive output from the stock. Therefore, some consideration for reducing mortality of the largest female Atlantic blue marlin is appropriate. Future research should attempt to clarify the reproductive potential of large female blue marlin to enhance management options for this species.

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