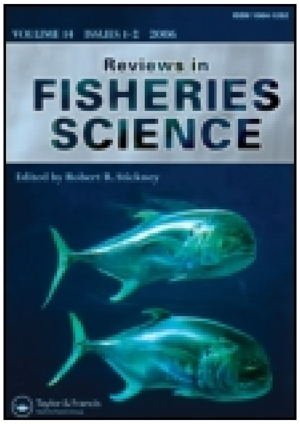

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The Recovery of Atlantic Swordfish: The Comparative Roles of the Regional Fisheries Management Organization and Species Biology

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The Recovery of Atlantic Swordfish: The Comparative Roles of the Regional Fisheries Management Organization and Species Biology

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Regional fisheries management organizations (RFMO) are often criticized for ineffectual management of high-seas fisheries resources. However, in the case of the two Atlantic swordfish stocks occurring in the North and South Atlantic, those stocks have rebuilt to the B_{MSY} objective of the responsible RFMO, the International Commission for the Conservation of Atlantic Tunas (ICCAT). The relative contribution of the management actions of the RFMO and biological characteristics of swordfish stocks are evaluated in relation to the recovery of the stocks. It is concluded that while swordfish have characteristics that promote stock resilience (including relatively fast growth, and spatially- and temporally-dispersed spawning), positive management actions combined with a period of relatively good recruitment were essential to achieve the rebuilt outcome. The challenges that the RFMO faces to maintain the stocks in the rebuilt condition are described, and some possible additional measures discussed.

Keywords stock recovery, Atlantic swordfish, regional fisheries management organizations

1 INTRODUCTION

The management of high seas fisheries resources is vested globally with 17 international bodies, known as regional fisheries management organizations (RFMO). In recent years, the performance of these organizations in meeting their conservation objectives has been criticized. In a wide-ranging review, Cullis-Suzuki and Pauley (2010) considered both the theoretical and practical performance of the RFMO with mandates for management of high-seas fisheries worldwide. The theoretical performance of RFMO was determined by assessing how well organizations scored against 26 criteria that the authors considered to be RFMO best practices. The assessment considered the current state of the stocks through biomass and fishing mortality reference points and biomass trends through time, and the overall mandate of the RFMO. Results showed low performance of RFMO for both the theoretical and practical assessments, i.e., average scores of 57% and 49%, respectively. Concerning

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the practical performance of the RFMO, they concluded that two-thirds of stocks fished on the high seas and under RFMO management are either depleted or overexploited. These results, however, can vary depending on the mix of stocks and RFMO considered, as well as the timeframe for stock status evaluations, as both the fish stocks and fisheries harvesting them are dynamic. Cullis-Suzuki and Pauley (2010) also noted a disconnect between theoretical and practical performance of RFMO, suggesting a disparity between organization intent and action.

Other authors have focused on the performance of individual RFMOs. For example, Straker (2009) examined the functioning of the International Commission for the Conservation for Atlantic Tunas (ICCAT), the RFMO responsible for management of tuna and tuna-like species in the Atlantic. Straker (2009) concluded that the organization was performing well with respect to the collection and analyses of fisheries information, the provision of recommendations to its parties, and the dissemination of information—all important aspects of its mandate. However, the author concluded that the organization was failing to make substantial progress in effective conservation of tuna and tuna-like species within its mandate, due to an inability to undertake difficult management actions. Rayfuse (2005) also commented on the apparent inability of RFMO to effectively deal with compliance issues, particularly in relation to illegal, unreported, and unregulated (IUU) fishing activities.

In spite of such criticisms, RFMO can point to some recent successes. For example, ICCAT has recently documented the rebuilding of both North and South Atlantic swordfish stocks (Anon., 2010; Figure 1), against the convention objective of maintaining the stocks at levels that support maximum sustainable yield (MSY). This rebuilding is significant both from an RFMO and worldwide perspective, since although Atlantic production of most tuna stocks represents only about 10% of worldwide production, production of Atlantic swordfish represents about half of the worldwide swordfish total (Figure 2).

In this article, we document the management actions that may have contributed to stock rebuilding for the Atlantic swordfish stocks. We also evaluate, in a comparative sense, aspects of the biology of Atlantic swordfish relative to other large pelagic species that may contribute to the resilience of the species and its ability to recover from an over-exploited state. By critically reviewing both the biology of swordfish and ICCAT management actions, we aim to comment on whether it is appropriate to conclude that the RFMO can claim success in rebuilding those stocks.

2 BIOLOGICAL ATTRIBUTES AFFECTING REBUILDING POSSIBILITIES

2.1 Reproduction

Swordfish ovaries are paired, elongated bi-lobed asymmetrical organs lying in the posterior half of the body cavity. The

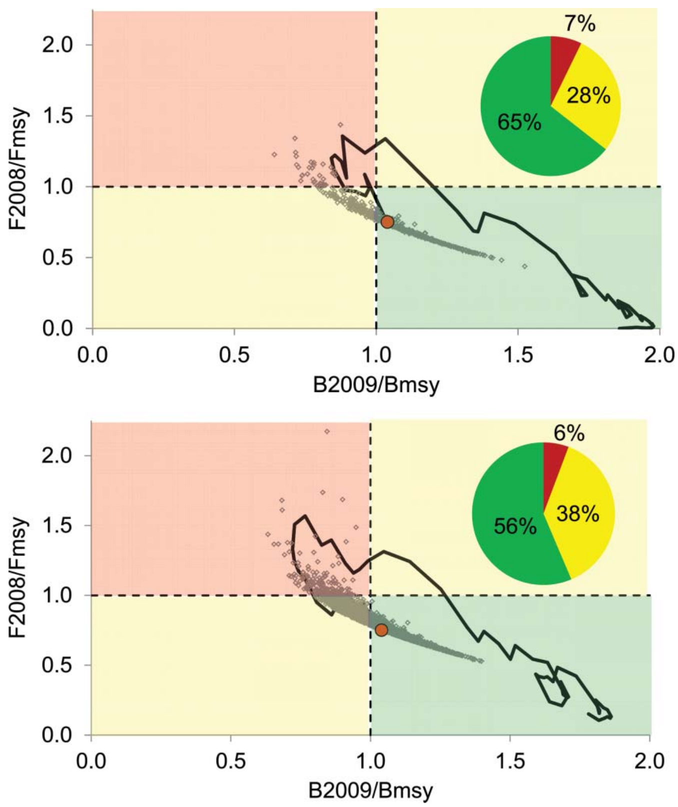

Figure 1 Summary figure of the current southern (upper) and northern (lower) Atlantic swordfish stock status which includes different representation of the bootstraps results of the base surplus production model: percentage, phase-plots (red dot corresponds to the deterministic result) and stock status trajectories for the period 1950–2008. The x-axis represents relative biomass, and the y-axis relative exploitation rate. The green quadrant represents the "healthy zone," with stock status consistent with ICCAT's objectives: biomass relative to MSY >1.0, and exploitation rate relative to MSY <1.0. Yellow quadrants reflect either depletion or overfishing, while red quadrant signifies both depletion and overfishing. The pie charts reflect the distribution of bootstrap estimates of current stock status within a given stock state.

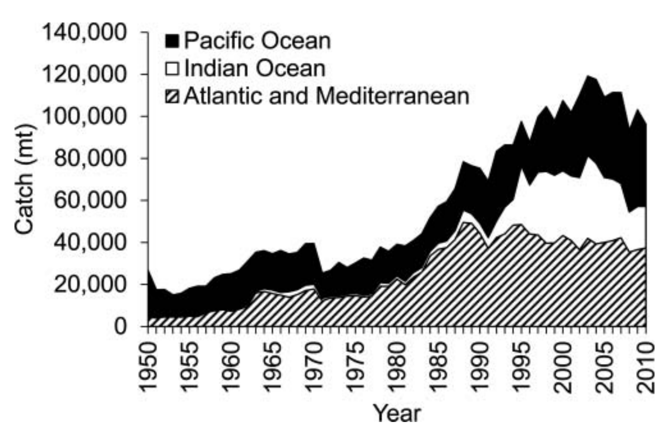

Figure 2 Worldwide production of swordfish since 1950. While Atlantic production has declined from peak levels in the late 1980's, it remains about half of the recent world-wide production.

ovaries conform to the general pattern for teleost fishes, which consists of ovigerous lamellae with oogonia and oocytes at different stages of development (Arocha, 2002; Corriero et al., 2004). As the ovaries mature, continuous oogenesis is displayed, in which oocytes at different stages of development are found simultaneously indicating that swordfish has asynchronous oocyte development (Arocha, 2002; Corriero et al., 2004); classifying it as a species with indeterminate spawning style in which "realized fecundity," i.e., number of eggs spawned per season, is the product of the spawning frequency and batch fecundity (Kraus et al., 2000; Kjesbu et al., 2003). The spawning style observed in swordfish is common in species showing a long spawning period (≥90 days), like some tuna species and several billfish species (e.g., *Thunnus thynnus, T. albacares, T. obesus, Makaira nigricans*, and *Tetrapturus albidus*). The spawning frequency for North Atlantic swordfish was estimated at 2.6 days (Arocha, 1997), similar to estimates of other swordfish stocks (3.0 days [Young et al., 2003]; 2.8 days [Poisson and Fauvel, 2009b]), and to the blue marlin *Makaira nigricans* (2.4–2.9 days [Sun et al., 2009]), but a lower rate than those estimated for several tuna species (*T. thynnus, T. macoyii, T. albacares, T. obesus*) in which the spawning frequency estimated was <2.0 days (Medina et al., 2002; Farley and Davis, 1998; Schaefer, 1998; Chu, 1999).

Male testes constitute a slender ribbon-like bi-lobed organ when undeveloped, with longitudinal sperm ducts medially, and if cross-sectioned they appear solid. Developed testes become swollen and convoluted with sperm maturation and recrudescence towards reproduction. From the inner sides of the lobes of the testes the primary sperm ducts extend, which unite close to the anal opening (Arocha, 1997). The structural organization of the swordfish testis is considered as an unrestricted spermatogonial testis type (Grier et al., 1980; Corriero et al., 2007). It has been suggested for some teleost fishes that spermatogenesis not completed entirely within the cysts (Mattei et al., 1993) can lead to asynchronous development of male sex cells and probably results in a protracted spawning period in males. In swordfish, spermatogenesis appears to be of the cystic type (Corriero et al., 2007), in which all stages of spermatogenesis occur within the cysts.

The reproductive cycle of North Atlantic swordfish females can be rebuilt from microscopic examination combined with measurement of whole oocytes and cytology of the gonads (Arocha, 1997; Taylor and Murphy, 1992; Arocha 2007). In the subtropical waters (13°–35°N) of the western North Atlantic, swordfish are reproductively active throughout the year but with marked peak spawning in different months and in different areas (Figure 3). In the area southwest of the Sargasso Sea, swordfish in active non-spawning condition (vitellogenic oocytes in the ovaries) begin to appear in early December. Spawning individuals, with hydrated oocytes and/or post-ovulatory follicles,

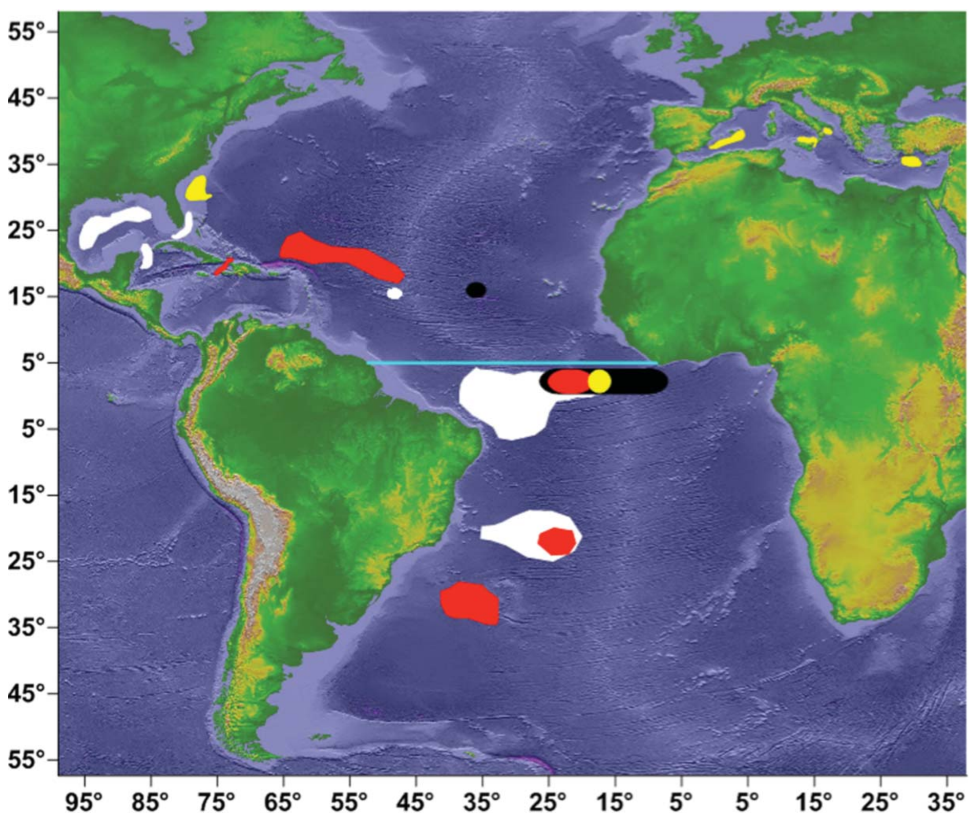

Figure 3 Swordfish seasonal spawning areas in the Atlantic Ocean and the Mediterranean Sea. Stock boundary line at 5°N. (A) North stock, December–February (filled red), March–May (filled white), June–August (filled yellow), and September–October (filled black); (B) South stock, January–March (filled red), April–June (filled white), July–September (filled yellow), and October–December (filled black). While the knowledge of areas of spawning is not considered complete, it is particularly so for the Mediterranean.

have been found from late December to May. In the areas of the Gulf of Mexico/Caribbean passages and southeastern U.S., active non-spawning individuals appeared in early December, and spawning individuals were observed from late December to March in the Gulf of Mexico/Caribbean passages. In the southeastern U.S., swordfish in active non-spawning condition appeared in February–March and spawning individuals peaked from April through July. In the tropical waters ($<14°$N) of the western North Atlantic, swordfish appeared inactive during most of the year, but in November, individuals in active non-spawning condition were observed and occasional spawning individuals were found in December. While in the temperate ($>35°$N) waters of the North Atlantic, swordfish have been found to be reproductively inactive during most of year, with few exceptions in the eastern side (Mejuto, 2007). The reproductive cycle of the North Atlantic swordfish males is poorly known, and most observations are macroscopic. Most males appeared "always ready," with a permanent flow of seminal fluid, in the subtropical waters of the western North Atlantic through most of the year. In the rest of the North Atlantic, the testes from individuals observed did not show the "always ready" condition.

2.1.1 *Fecundity*

The mean estimated relative batch fecundity for North Atlantic swordfish was 32.2 oocytes g^{-1} (13.2–61.9 oocytes g^{-1} [Arocha, 1997]); while no clear trend in relation to size and age was observed, larger and older individual tend to display higher values. Similar estimates were observed in swordfish from the Indian Ocean ($\bar{x} = 44.1$ oocytes g^{-1}, 25.1–71.8 oocytes g^{-1} [Poisson and Fauvel, 2009b]), but Mediterranean and South Atlantic swordfish displayed the highest estimates observed ($\bar{x} = 87.4$ oocytes g^{-1}, 40.6–146.5 oocytes g^{-1} [De la Serna et al., 1996]; $\bar{x} = 74.6$ oocytes g^{-1}, 41.1–106.6 oocytes g^{-1} [Hazin et al., 2001]). Estimated relative batch fecundity for several tuna species were also similar or within the range of the estimates of North Atlantic swordfish: *T. obesus* 31 oocytes g^{-1} (bigeye tuna [Nikaido et al., 1991]); *T. macoyii* 57 oocytes g^{-1} (southern bluefin tuna [Farley and Davis, 1998]); and *T. albacares* 67 oocytes g^{-1} (yellowfin tuna [Schaefer, 1998]). *T. thynnus* from the Mediterranean and eastern Atlantic displayed similar estimates (Atlantic bluefin tuna, $\bar{x} = 93$ oocytes g^{-1}, 93–137 oocytes g^{-1} [Rodriguez-Roda, 1967; Medina et al., 2002]) to those observed for Mediterranean swordfish.

Reported estimates of mean batch fecundity of North Atlantic swordfish (>160 cm lower jaw fork length [LJFL]) ranged from ~1–9 million oocytes (Arocha, 2007), which is similar to other swordfish stock estimates (Young et al., 2003; Poisson and Fauvel, 2009b) and to *M. nigricans* (Atlantic blue marlin) from the tropical western Atlantic (Martins et al., 2007). As indicated previously, "realized fecundity" in species with an indeterminate spawning style can be accurately estimated from the batch fecundity (using only migratory-nucleus stage and unvoluated hydrated oocytes) and the spawning frequency. Unfortunately, few estimates are available that fulfill the above conditions. In North Atlantic swordfish, the estimated "realized fecundity" for a fish of 200 cm LJFL was 224 million oocytes and up to 709 million oocytes for a 250 cm LJFL fish. This estimate is based on the conditions indicated above and detailed in Arocha (1997) and Arocha and Bárrios (2009), and is somewhat similar to the estimated "realized fecundity" of 328 million oocytes for a 225 cm LJFL swordfish from the Indian Ocean (Poisson and Fauvel, 2009b). However, these estimates are higher than those estimated for a ~225 cm LJFL fish from the southwestern Pacific Ocean (21–40 million occytes [Young et al., 2003]), for the most part because the spawning frequency considered for the estimate included only the months during the peak of the spawning season, thus reducing the spawning frequency to <2 days. In tuna species, reported estimates of "realized fecundity" for *T. albacares* from the eastern Pacific ranged from 223 to 671 million oocytes for individuals of 92 cm and 123 cm fork length (Schaefer, 1998); but for western Atlantic *T. thynnus* reported mean "annual" fecundity was in the order of 30–75 million oocytes (Baglin and Rivas, 1977; Baglin, 1982). This estimate, however, may be biased because it included counts of oocytes that had not entered their final stages of maturation.

2.1.2 *Size and Age at Maturity*

Reliable estimates of size/age at maturity require accurate selection of spatial and temporal spawning areas for sampling, a statistically robust procedure for the estimation of the maturity fraction (Kjesbu et al., 2003) and that the mature proportion is defined with precise criteria (histology versus gonad indices). The available L_{50} (LJFL at which 50% of the fish are mature) estimates for swordfish are given in Table 1. While most of the estimates are considered to be reliable on the basis of the conditions expressed previously, the L_{50} estimates for swordfish in the Atlantic Ocean, including the Mediterranean Sea, are quite variable. These differences may be caused by a combination of maturity classification procedures and consideration of different stock units. Also, different area samples were observed where maturation and spawning processes can occur frequently, seasonally, or sporadically during the year, thereby affecting the proportion between mature and resting female fractions. The L_{50} estimate observed for the North Atlantic swordfish stock defined the mature fraction based on a combination of histology, and oocyte size distributions (Arocha, 1997; Arocha, 2007), while the two similar L_{50} estimates obtained for the South Atlantic stock were based on a gonad index associated with microscopic gonad development (Hazin et al., 2002; Mejuto, 2007). Regardless of these differences in procedures, it is noteworthy that most of the observed spawning occurs in the warm, western side of the Atlantic. In the North Atlantic, spawning was described to take place in subtropical waters (Arocha, 1997; Arocha, 2007); gonadal indices also indicated spawning events in some western tropical waters (Mejuto, 2007). In the South Atlantic stock, intense spawning takes

Table 1 Swordfish (*Xiphias gladius*) estimates of size at first maturity (L_{50}) for several known stocks around the world

Stock	Geographical area	Females L_{50} LJFL (cm)	Males L_{50} LJFL (cm)	Sources
North Atlantic Ocean	Western North Atlantic (subtropical waters)	178.7	128.7	Arocha (1997); Arocha (2007); Taylor and Murphy (1992)
	Western North Atlantic (Straits of Florida)	182	112	
South Atlantic Ocean	central tropical Atlantic	146.5	—	Mejuto (2007); Hazin et al. (2002)
	western central Atlantic (off Brazil)	156	—	
Mediterranean Sea	Mediterranean Sea	142.2	—	De la Serna et al. (1996)
North Pacific Ocean	central North Pacific (around (Hawaii)	162.2	117.2	DeMartini et al. (2000); Wang et al. (2003)
	western North Pacific (around Taiwan)	168.2	—	
Indian Ocean	southwestern Indian ocean (Reunion Island)	170.4	119.9	Poisson and Fauvel (2009a); Poisson and Fauvel (2009b)

place more regularly in western tropical waters but spawning events were also observed to reach 25°S during some months of the year (Hazin et al., 2002; Mejuto, 2007).

In the western North Atlantic, examination of the ovaries and testes showed maturation schedules in which females were unlikely to mature before age 5, while males matured very early at ages 1–2 (Ehrhardt, 1992; Arocha, 1997; Arocha et al., 2003). In the South Atlantic and in the Mediterranean Sea, maturity (L_{50}) in females occurred at about ages 3–4, depending on the growth function used in extrapolating age from length (Tserpes and Tsimenides, 1995). In the North Pacific, female swordfish reached maturity at age 5 and males at age 2 according to the growth function for the area (Sun et al., 2002). In the western Indian Ocean, females attained maturity (L_{50}) at ages 6–7 (Poisson and Fauvel, 2009a) and males at ages 2–3 according to the growth function estimated for the same area (Vanpouille et al., 2001). On the basis of the present information, female swordfish in the northern hemispheres (Atlantic and Pacific Oceans) seem to mature (L_{50}) at about the same age. However, there is still uncertainty about the estimated age of first maturity for the South Atlantic stock. Despite the large sampling based on gonadal indices and the identification of broad spawning areas south of 15°S (Amorim and Arfelli, 1980; Mejuto, 2007) where larvae have also been reported (Ueyanagi et al., 1970), the absence of an acceptable growth function for the southern stock does not allow this parameter to be calculated. The stock from the Indian Ocean seems to show a delayed maturity schedule at age compared to the Atlantic, although the L_{50} female estimate is similar to the North Atlantic stock. In contrast, there is very little information on swordfish maturity in the South Pacific, an unfortunate outcome considering the important fishery off Chile and eastern Australia (Young et al., 2003; Barbieri et al., 1998; Mejuto et al., 2008). Estimates for 50% maturity have been reported at age 5 for the southeastern Pacific (Hinton and Maunder, 2006).

2.1.3 Area and Time of Spawning

Spawning areas for Atlantic swordfish were located on the basis of a combination of sexual attributes that included histological and microscopic gonad examination, gonad condition indices, and patterns of eggs and larval distribution (Arocha, 1997; Govoni et al., 2003; Mejuto, 2007). Three regional spawning areas are widely recognized, one for each of the three stocks (Figure 3). For the North Atlantic stock, the principal reported spawning area is located in the subtropical area between 14° and 35°N and west of 50°W. For the Mediterranean stock, the main spawning area appears to be restricted to the area between 35° and 40°N and west of 30°E (Figure 3). For the South Atlantic stock, the main spawning area is located in the tropical equatorial Atlantic between 10° and 5°S and west of 20°W (Corriero et al., 2004; Arocha, 2007; Mejuto, 2007; Figure 3). Specific oceanographic conditions within each region are likely important for spawning and the spawning site within each basin likely represents a balance between requirements for survival of the larvae and the physiological limitations of spawning fish. The timing of spawning in the region appeared to be correlated with sea surface temperatures (SST) >23–24°C in tropical and subtropical waters and the displacement of the 24°C SST isotherm in the northern and southern hemisphere (Arocha, 1997; Arocha, 2007; Mejuto, 2007). However, the isotherm at 50-m depths has been suggested as a better indicator for the areas of potential spawning than the sea surface temperature (Mejuto, 2007). As temperature in the subtropical waters of the western North Atlantic varied seasonally from 22–29°C (Weidner et al., 1999), spawning appeared to occur progressively in time and space when water temperatures of 24–25°C were displaced at different depths (Arocha, 1997). This effect began in December–February southwest of the Sargasso Sea and continued through the Caribbean passages in March–May, ending in the southeastern U.S. in the summer months (Taylor and Murphy, 1992; Arocha, 2007). In the South Atlantic swordfish, spawning appeared to occur mostly around the equator (5°N–10°S) and west of 20°W throughout the year (Amorin and Arfelli, 1980; Mejuto, 2007) when temperatures in the surface layers remained >24°C (Carton et al., 1996; Conkright et al., 1998). Some authors have suggested a higher intensity of spawning in the first and second trimester of the year (Amorim and Arfelli, 1980). However, others indicate that in some areas, spawning occurs throughout the year, while in other adjacent areas spawning events are seasonal or sporadic depending on the expansion or contraction of the warm water masses throughout the year (Mejuto, 2007). In the Mediterranean Sea, spawning begins in June when sea surface temperatures reach 24–26°C and by the end of August most fish have spawned (Palko et al., 1981; Cavallaro et al., 1991; Corriero et al., 2004).

Estimated spawning time in the western North Atlantic based on females with hydrated oocytes in the gonads and a spawning index based on ratios that standardize gonad mass to body size (Taylor and Murphy, 1992; Arocha, 1997, 2007) revealed two spawning groups. The first one occurred in open ocean waters southwest of the Sargasso Sea; the second in waters near land masses and fast current systems. Spawning in open ocean waters began in December and peaked in January–February at 18°–25°N, and continued in April–May at 15°–13°N (Arocha, 1997, 2007). Mature swordfish close to land and strong currents spawned from December to March in the Windward Passage and Yucatan Channel, and from May to August in the Straits of Florida up to 32°N (Taylor and Murphy, 1992; Arocha, 1997, 2007). In the case of the neighboring Mediterranean swordfish stock, spawning occurs from May to August and the existence of three principal spawning areas, one in each region of the basin (eastern, central, and western Mediterranean) has been suggested (Cavallaro et al., 1991; Macías et al., 2005; Tserpes et al., 2001; Tserpes et al., 2008).

In the North Atlantic, larvae (<20 mm) have been collected from south of the Sargasso Sea, with peak occurrences from February to April (Tåning, 1955); larvae then transit to the Lesser Antilles and into the Caribbean during the first half of the year (Grall et al., 1983; Govoni et al., 2003). The abundance of larvae in the Lesser Antilles (Tibbo and Lauzier, 1969; Markle, 1974) may represent a transitional zone between open water spawning site and nursery area of the Caribbean Sea (Arocha, 1997, 2007). Young larvae originating from spawning in the Gulf of Mexico remain in that region during the spring/summer season (Govoni et al., 2003); the larval abundance in the Charleston Bump area (southeastern U.S. coast [Govoni et al., 2000]) also indicate a spawning site in the southeastern United States.

Information on spawning time in the South Atlantic is limited. The gonadosomatic index (GSI) used for determining the seasonal spawning pattern was based on index values for fish near spawning condition (>5.0 cm LJFL and >150 cm LJFL [Corriero et al., 2004; Arocha and Lee, 1993]). Mejuto (2007) determined GSI values for 558 South Atlantic female swordfish (150–270 cm LJFL) and observed developed ovaries throughout the year in the tropical band between 5°N–10°S. Female swordfish with GSI values >5.0 were most common during the first half of the year (January–June), with the GSI increasing progressively from the first trimester to the next, in which spawning fish (GSI > 5.0) represented >50% of the sexually active females. Analogous to the North Atlantic spawning time, in the subtropical waters of the South Atlantic (>15°S), GSI spawning values begin to increase in October–December, peak in January–March, decline in April–June, then drop to a very low level in July–September.

Reports of South Atlantic swordfish larvae are scarce, limited only to specimens found off Fortaleza and Recife, Brazil, and around Trinidad and Martin Vaz Islands (Brazil offshore islands) in November–April and in the center of the tropical Atlantic (∼3°N–30°W) from May to October (Ueyanagi et al., 1970).

Mediterranean swordfish spawning time, estimated from GSI and the developmental phase of oocytes in maturing ovaries, revealed that spawning began in the western Mediterranean when individuals with vitellogenic oocytes in their ovaries and GSI ∼5.0 appear around the Balearic Islands, Spain, in April–June (de la Serna et al., 1992, 1996). Spawning began in June and continued through August, when a GSI >7.0 was observed. Most of the females with hydrated oocytes and GSI >9.0 were reported from the southern Tyrrhenian Sea, the northern Ionian Sea and the Strait of Messina off southern Italy (Cavallaro et al., 1991; Corriero et al., 2004). Spawning swordfish with GSI >7.0 was also found in the eastern Mediterranean (southeast of Rhodes Island, Greece) (Tserpes et al., 2001). Spawning time in the Mediterranean Sea is also corroborated by known reports of swordfish larvae found in southern Italy collected mostly during July, in particular in the southern Tyrrhenian Sea, Ionian Sea, and the Strait of Messina (Sanzo, 1922; Cavallaro et al., 1991; Potoschi et al., 1994).

2.1.4 Other Parameters and Behavior Related to the Reproductive Process

The spatial and temporal variability in the overall sex ratio and in the sex ratio at-size of swordfish has been reported since the 1940s (Rich, 1947) but its biological interpretation was not elucidated until the end of the 20th century. Initial studies identified differences in sex ratio around Cuba, suggesting that the seasonal variability observed was due to the high abundance of medium-sized males along with large females during the reproductive processes in that area (Guitart-Manday, 1964). Later studies related sex ratio patterns and sex ratio at-size to the temperature of surface water masses (Becket, 1974; Hoey, 1986). Other studies confirmed similar patterns of sex ratio at-size in temperate areas of the eastern North Atlantic (García and Mejuto, 1988). On the basis of those studies, a hypothesis of "size-temperature mediated sexual segregation" was put forth by Hoey (1991, p. 431) that explained the variability in the sex ratio at-size reported in the different areas of the western North Atlantic.

Several studies undertaken in the 1990s described similar patterns of sex ratio at-size between regions and fleets across the Atlantic Ocean (Arocha and Lee, 1996; Lee, 1992; Mejuto and de la Serna, 1997; Mejuto et al., 1994, 1995, 1998; de la Serna et al., 1992, 1993; Stone and Porter, 1997; Turner et al., 1996, 1997). An explanation for some of the differences between the sex ratios among sizes was based on the differential growth rates between males and females (Restrepo, 1991) since females attain a larger maximum size (L_{max} and L_∞) and exhibit higher growth rates than males. This was believed to explain that the larger-sized fishes seen in the commercial catches had a greater probability of being females, while males of different ages were mainly found within a smaller number of intermediate size classes. While the difference in growth between males and

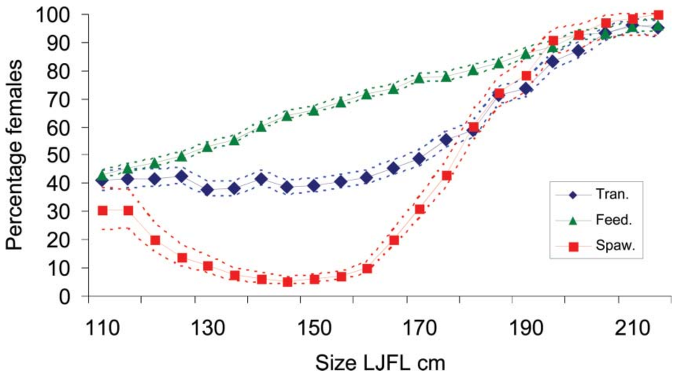

Figure 4 Patterns of mean sex-ratios at size identified for sizes ranging from 110–215 cm LJFL (solid coloured lines) and their respective confidence intervals of 95% (dotted coloured lines). Tran. = transitional. Feed. = feeding. Spaw. = spawning.

females may be explained by modeling the differences of sex ratio between sizes, it did not provide a solid explanation to justify the wide variability in sex ratio at-size between some of the regions for the same size classes. Similarity analyses of sex ratio at-size between regions were able to identify characteristic clusters in the Atlantic Ocean and other oceans (Mejuto et al., 1994, 1995, 2006, 2008). The sex ratio at-size patterns obtained for the different regions analyzed were classified into three characteristic groups in terms of aspects related to the environment and species behavior, labeled spawning, feeding, and transitional (Mejuto et al., 1998; Mejuto, 2007; Figure 4). These types of patterns were also observed in the western North Atlantic, the Mediterranean Sea, and the Indian and Pacific Oceans (Arocha, 1997; Tserpes et al., 2001; Mejuto et al., 2006, 2008). In regions with a sex ratio at-size that reflects a "spawning" pattern (spoon shaped; Figure 4), the caught swordfish were comprised of females with mature gonads along with a strong prevalence of males in the intermediate size classes. The spoon-shaped pattern observed in the "spawning" areas has been described as being due to the higher concentration of males (which are several times more abundant than females) in the spawning grounds owing to "courting" and "coupling" behavior for the fertilization of the eggs released during the spawning processes (Palko et al., 1981; Mejuto, 2007). Genetic studies conducted to test whether samples from regions identified as spawning and feeding grounds were more closely related to each other than to samples from any other region (Alvarado Bremer et al., 2005) supported the biological regions defined on the basis of sex ratios at size data. Recent studies (Poisson and Taquet, 2001; Mejuto et al., 1998) have indicated that the swordfish sex ratio at-size pattern is a biological characteristic intrinsic to the species, conditioned by its environmental requirements and the layers it inhabits, in such a way as to allow or favor basic physiological and biological processes. The differences between the sex ratios at-size seem to support the hypothesis that the spatial migration of the total fraction of females tends to cover (in terms of probability) a broader geographic area to sustain its energy requirements in order to support the high production of eggs, whereas the migration of males would be generally more restricted and conditioned by the lower average body biomass and the lower energy requirements in comparison to the females to produce spawning products.

2.2 Growth

Data on the age and growth of swordfish are very important input parameters for assessing stock trends when age-structured models are used. Most of the studies on swordfish growth have been carried out in North Atlantic waters since the mid-1980s using mainly anal fin spine sections (e.g. Berkeley and Houde, 1983; Riehl, 1984; Ehrhardt et al., 1996; Esteves et al., 1995; Arocha et al., 2003). Several other studies on growth were also carried out in the Pacific Ocean (e.g. Castro-Longoria and Sosa-Nishizaki, 1998; Sun et al., 2002; Valeiras et al., 2008; Young and Drake, 2003, 2004). The information from the Indian Ocean is more limited (e.g. Poisson and Taquet, 2001; Wang et al., 2010).

Most studies using anal fin spines have been based on the methodology initially described by Berkeley and Houde (1983) and later refined by Esteves et al. (1995), Ehrhardt et al. (1996), and Tserpes and Tsimenides (1995). Ehrhardt (1992) reported that the von Bertalanffy growth function did not adequately represent swordfish growth. Tserpes and Tsimenides (1995), Sun et al. (2002), and Arocha et al. (2003) proposed Chapman's generalized model to estimate growth parameters.

Results based on age interpretations from fin spines suggest that size at age is generally quite similar in most of the Atlantic studies and among oceans for ages less than five years old. However, significant differences were reported in some cases with the slowest growth pattern being described from the westernmost Pacific areas around Australia (Young and Drake, 2004). Great differences in some key biological parameters, such as growth or reproduction, are not initially expected among stocks of large migratory pelagic fish with very broad and frequently overlapping areas of distribution and/or mixing. The respective area-time sampling coverage, the different methodologies used among authors, the lack of standardized criteria available to interpret the annuli in hard parts, and the respective statistical approaches, could explain the differing results reported by some of the authors.

Most of the studies based on fin spines have not yet been validated by the marginal increment analysis or other methods. It has not been generally possible to verify the relationship between annuli formation on the spines and seasonal growth phases with a reasonable degree of certainty. The highly migratory behavior of this species and its choice of different areas-habitats during respective periods of its annual or multiannual migratory cycle (e.g., feedings versus reproduction) make it difficult to assume and validate a plausible general hypothesis on the causes of the formation of these annuli with a stable annual pattern. Although in some areas seasonal migratory behavior that is markedly clear and stable has been observed between years, this behavior cannot be generalized to all the geographic areas studied.

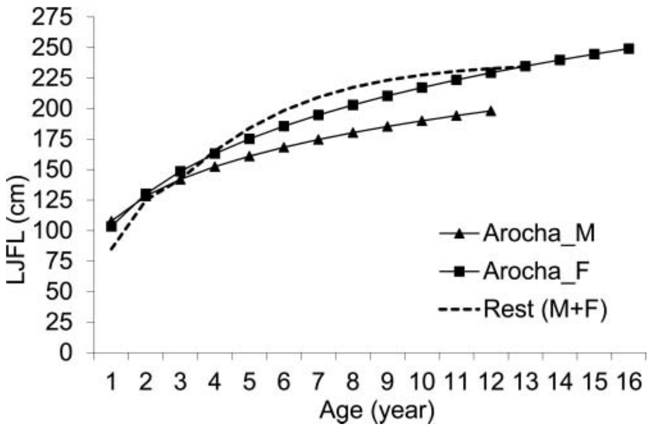

Figure 5 Some estimates of mean size at age for the North Atlantic swordfish. (A) Age-size by sex (males = M, females = F) obtained from the analysis of anal fin spines using a Chapman's generalized fit (Arocha et al., 2003). (B) Age-size (males and females combined) based on the tag-recapture data provided by the ICCAT from their respective national programs (data from Restrepo, 1990).

On the basis of all the growth studies performed in the North Atlantic, it can be inferred that swordfish growth is relatively rapid and sexually dimorphic (Figure 5). The longevity of swordfish is thought to rarely exceed 25 years of age. Females generally reach a larger maximum size than males and large individuals are usually female—with this probability increasing with size. These characteristics seem to be common in all the swordfish stocks studied in the different oceans. In the North Atlantic, L_∞ (asymptotic length) values as high as 375 cm and 300 cm LJFL were obtained for females and males, respectively (Arocha et al., 2003) although this value is sensitive to the number of large fish observed and the method for fitting sparse data, especially for males. Individuals as large as 338 cm LJFL and weighing 440 kg round weight (RW) were reported from observations in the North Atlantic in 2011, although individuals even greater in size—up to 536 kg—have been reported in the Pacific Ocean in historical time series (Nakamura, 1985).

Considering all of the studies available using hard parts, after averaging their estimates and including both males and females, generally speaking, a swordfish would probably reach a LJFL value of around 97 cm (roughly equivalent to 10 kg RW) during its first year of life, 160 cm (roughly equivalent to 53 kg RW) at 5 years of age, and it would exceed 200 cm at 9 years of age. However, it must be remembered that these summarized growth values differ between sexes and studies.

Differential growth between males and females can explain the different sex ratio observed between sizes, since the larger individuals are more likely to be females. Differential growth by sex also has implications for other factors, including female spawning stock biomass estimates, and differential migratory and spatio-temporal distribution patterns for males and females (see Section 2.1.4). This complex behavior of the swordfish linked to the respective migratory habits of males and females could significantly confound interpretation of annulus formation and age from hard parts.

Other growth studies have used otoliths (saggitae), size frequencies, or vertebrae (see Esteves et al., 1995). Studies based on the readings of the relatively tiny otoliths have not often been used by investigators in view of the substantial difficulty and high cost of obtaining these parts. This method is much more complex in terms of preparation, reading and interpretation than using anal fin spines, which are readily available from landed fish.

As an alternative method to the studies discussed previously, tag-recapture data gathered through national tag-recapture programs have been used. While these data contribute highly useful information, avoiding subjective interpretations of annuli readings and allowing for an indirect validation of the growth estimates obtained by means of other techniques, they present a general limitation in that they cannot easily inform on sex of fish for most of the observations. Therefore, the growth estimates based on tag-recapture data are only available as sex combined (Anon., 1989; Restrepo, 1990). Despite the complexity involved in tagging swordfish, the availability of representative conventional tag-recapture data by sex would be very useful in further growth studies and validations.

To evaluate the growth of swordfish in comparison with other large pelagic fish species occurring in the Atlantic, we show the growth of various major ICCAT species according to the most recently used growth models for those stocks, compared with North Atlantic swordfish (Figure 6). As a further comparison, we also include the growth curve from a 2011 study of striped marlin (*Tetrapterus audax*) in the Pacific, considered to be one of the fastest growing teleost species (Keller-Kopf et al., 2011). Swordfish growth is comparable to striped marlin at age 1, and is the fastest growing of the ICCAT species through age 8.

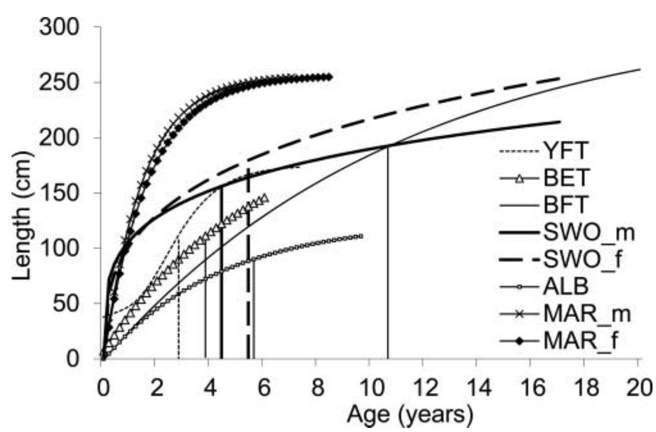

Figure 6 Growth curves and ages at first maturity (vertical lines) for various major species managed under the auspices of ICCAT. Data were obtained from the 2010 ICCAT manuals for yellowfin tuna (YFT; Gascuel et al., 1992, Albaret, 1977), bigeye tuna (BET; Hallier et al., 2005; Matsumoto and Miyabe, 2002), albacore tuna (ALB; Bard, 1981), bluefin tuna (BFT; Restrepo et al., 2010; Mather et al., 1995; Anon., 1997a) and swordfish (SWO; Arocha et al., 2003; Arocha and Lee, 1996; De Metrio et al., 1989; de la Serna et al., 1996). A recent study of striped marlin is also included (ST_MAR, Keller-Kopf et al., 2011), which is claimed by those authors to be one of the fastest growing bony fishes.

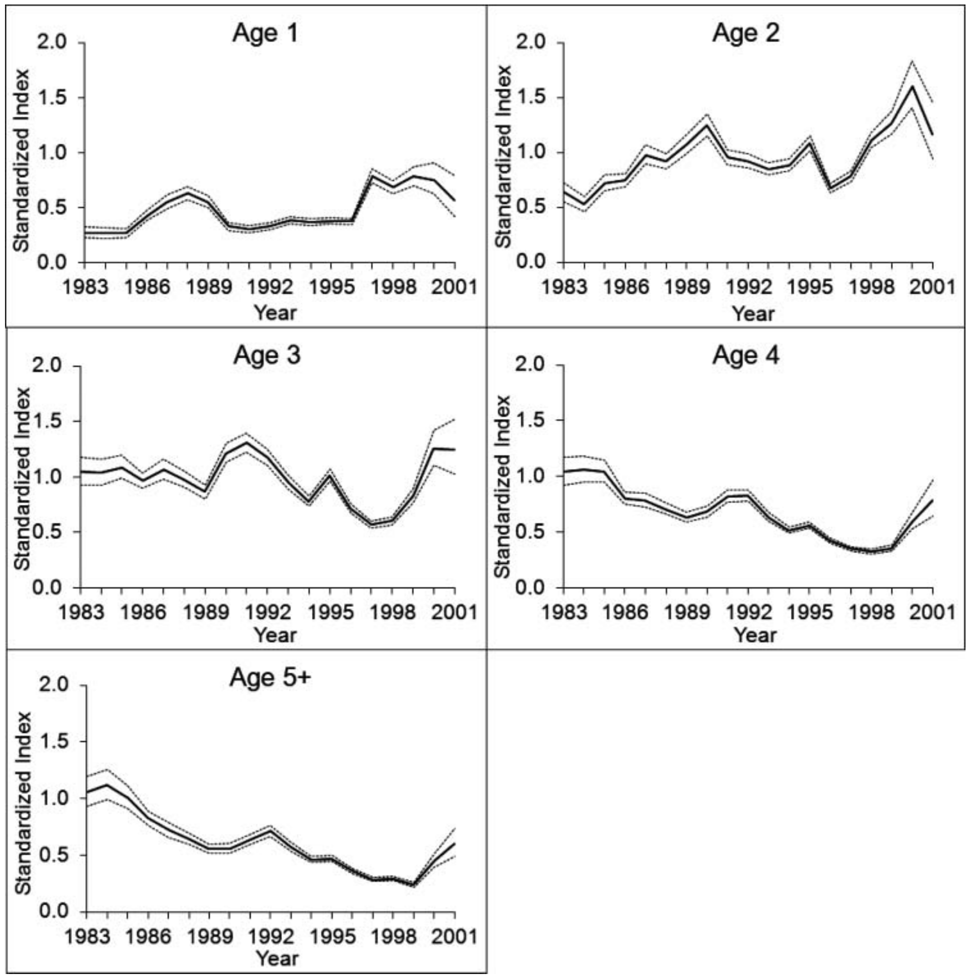

Figure 7 Annual standardized catch rates (standardized CPUE) in number of fishes by age (ages 1, 2, 3, 4, and 5+) per thousand hooks set observed in the Spanish surface longline fleet targeting swordfish in the Northern stock between 1983 and 2001 with confidence intervals of 95% (dotted lines). Adapted from Mejuto et al., 2003.

2.3 Recruitment

The standardized catch rates of age-1 swordfish by the Spanish longline fleet have been particularly useful as recruitment indicators (Mejuto et al. 2003). The series shows a substantial increase after 1996, despite the fact that this recruitment coincides in time with the lowest relative abundance of parent stock (5+) observed during the 1983–1996 period (Figure 7).

The reason for the increase in recruitment rates starting in 1996, coinciding in time with the lowest relative abundance of parent stock (5+) is still not completely understood. However, some of the possible causes have been attributed to changes in environmental-oceanographic factors (Mejuto, 2000, 2007) that were assumed to be more advantageous to recruitment processes starting in 1996 versus previous phases or periods. These favorable changes that took place as of 1996 may have had a particularly strong effect in the northwest Atlantic regions, which would, in turn, affect the Gulf Stream and other oceanographic events that are correlated with low negative values of the winter North Atlantic oscillation (NAO) index. Mejuto (2000, 2007) suggested that these processes may have played an important role in promoting the higher abundance of recruits owing to better viability of the stages of larvae development and pre-recruits starting in 1996, as opposed to the preceding decades. Those earlier periods were less conducive to high recruitment, and were coincident with a highly positive winter NAO phase especially between 1989 and 1995 that was almost unprecedented in terms of both the historical data observed and the data reconstructed using paleoclimatology (Mejuto, 2000, 2007). More up-to-date indices of abundance for recruiting fish are needed to further evaluate the hypothesis.

2.4 Behavior

Given that swordfish is a highly migratory species, fisheries that target swordfish adapt their fishing strategies and tactics according to the species migration patterns. Hence, the fishing fleets show a high degree of mobility, applying effort in regions with high concentrations of fish and the overall spatio-temporal distribution of the fishing effort is, to a large extent, determined by the species movements during its life-cycle (Ward et al., 2000 and references therein). Swordfish migration, however, is known to be complex and multi-directional (Palko et al., 1981), so the exploitable population is not always successfully followed by the fishery. Additionally, only part of the population (adults) migrates for reproductive reasons to well-known spawning grounds that are often highly exploited by the fisheries.

As described earlier, observations on the spawning grounds of the Atlantic (including the Mediterranean) and Indian Oceans, revealed the presence of a male biased sex ratio in the surface longline catches of large fish (Mejuto et al., 1995, 1998; Tserpes et al., 2001). This could be attributed to a lack of availability of females to the fishing gears due to a distinct behavior caused by physiological mechanisms prevailing during spawning. However, studies in the Atlantic indicate that the abundance of females into the spawning regions did not significantly differ compared with the abundances observed in adjacent regions, while the abundance of males were up to seven or eight times greater in the spawning regions compared with other adjacent regions (Mejuto, 2007). This would appear to indicate that if behavior differed resulting in varying availability in spawning and non-non spawning areas, that such differences were sex specific.

Juveniles are less migratory than adults and tend to congregate in warm waters, conducting seasonal migrations depending on the evolution of the isotherms in the near surface layers (Mejuto, 2003). Although there is inter-annual variability in the distribution pattern of juveniles, there are several recognized and persistent nursery areas in the western North Atlantic, for example in the Caribbean Sea the majority of the catch was small fish (ages 2–3, <130 cm LJFL), as well as in the Gulf of Mexico and the Charleston Bump area off the southeastern United States. It should be noted, however, that juvenile swordfish are aggressive during the first months of their life and are able to feed on relatively large prey (Peristeraki et al., 2005). In consequence, there is low size selectivity of the various types of surface longlines used and depending on the fishing area and season, longliners can regularly capture some undersized individuals (Mejuto, 2003). Data on the size composition of various Atlantic swordfish fisheries seem also to support this hypothesis (Arocha, 1997; Cramer, 1996). Studies in the Mediterranean have suggested that expected selectivity improvements through hook size increases are often not achieved (Tserpes and Peristeraki, 2010).

Apart from horizontal movements, it is well-documented that adult swordfish perform diel vertical migrations, with a general pattern of occurring in relatively deep water during daylight and coming closer to the sea-surface during night hours (Carey and Robinson, 1981; Sedberry and Loefer, 2001; Abascal et al., 2010; Dewar et al., 2011). This vertical migration makes the species available to the surface longlines only for some hours of the night (Bigelow et al., 2006). Swordfish occurrence in surface waters during the daytime is rather rare and it is related to periodic daytime basking effects that are more common in cooler water regions (Dewar et al., 2011). Harpoon fisheries exploit this behavioral feature but they are generally spatially limited and current harpoon catches now correspond to less than 5% of the total Atlantic catch (Anon., 2011), although historically they were more important. In general, the vertical distribution pattern is related to the light intensity and there are several studies suggesting a relationship between swordfish behavior and lunar cycle (Carey and Robinson, 1981; Hazin et al., 2002; Santos and Garcia, 2005; Loefer et al., 2007). Gear type and deployment depth are essential factors in explaining variation of swordfish catch rates in response to lunar phase (Dewar et al., 2011).

Unlike most tuna species, swordfish do not form schools or dense aggregations (Ward et al., 2000); thus they are not available to certain fishing gears, such as purse-seines, that are commonly used for the capture of several tuna and tuna-like species, although drift nets can be effective modes of capture.

2.5 Stock Structure

To assess and manage swordfish stocks, ICCAT considers that there are three distinct management units within its convention area: North Atlantic, South Atlantic, and Mediterranean Sea (Figure 8). A recent workshop dealing with stock structure of swordfish in the Atlantic and Mediterranean reviewed results of biological and genetic studies and tagging programs and concluded that the available data generally support these hypotheses (Anon., 2007a). For example, it was noted that the size of initial sexual maturity of swordfish differs significantly between the Mediterranean and the Atlantic, and that growth parameters differ significantly between the Atlantic and Mediterranean stocks (Tserpes and Tsimenides, 1995; Arocha et al., 2003). Recent genetic investigations also support these conclusions. Alvarado Bremer et al. (1999, 2005, 2007), Kotoulas et al. (2003), and Anon. (2007a) have shown the existence of a significant difference in the genetic structure of swordfish among the populations of the four regions: North Atlantic, South Atlantic, Mediterranean, and Indian Ocean, with a Mediterranean population significantly distinct from the others. The conclusion that three stocks exist within the ICCAT convention area is also based on the identification of distinct spawning areas for this species, three in the Mediterranean (Cavallaro et al., 1991; Macias et al., 2005; Tserpes et al., 2001, 2008), and the other two in tropical waters in the northwest Atlantic (Beckett, 1974; Arocha, 2007) and the South Atlantic (Amorim et al., 1980).

While the evidence for the current stock structure is compelling, the precise location of the management boundaries is less certain. ICCAT currently considers that the line dividing the stocks of the North and South Atlantic is situated at latitude 5°N. However, some studies have concluded that the boundary between these two stocks is located considerably further north, between 10°N and 20°N latitude (Chow et al., 2007). Similarly, the exact location of the boundary between the Mediterranean and the north Atlantic stocks has also been discussed. Some authors consider that a mixing area exists between these two stocks

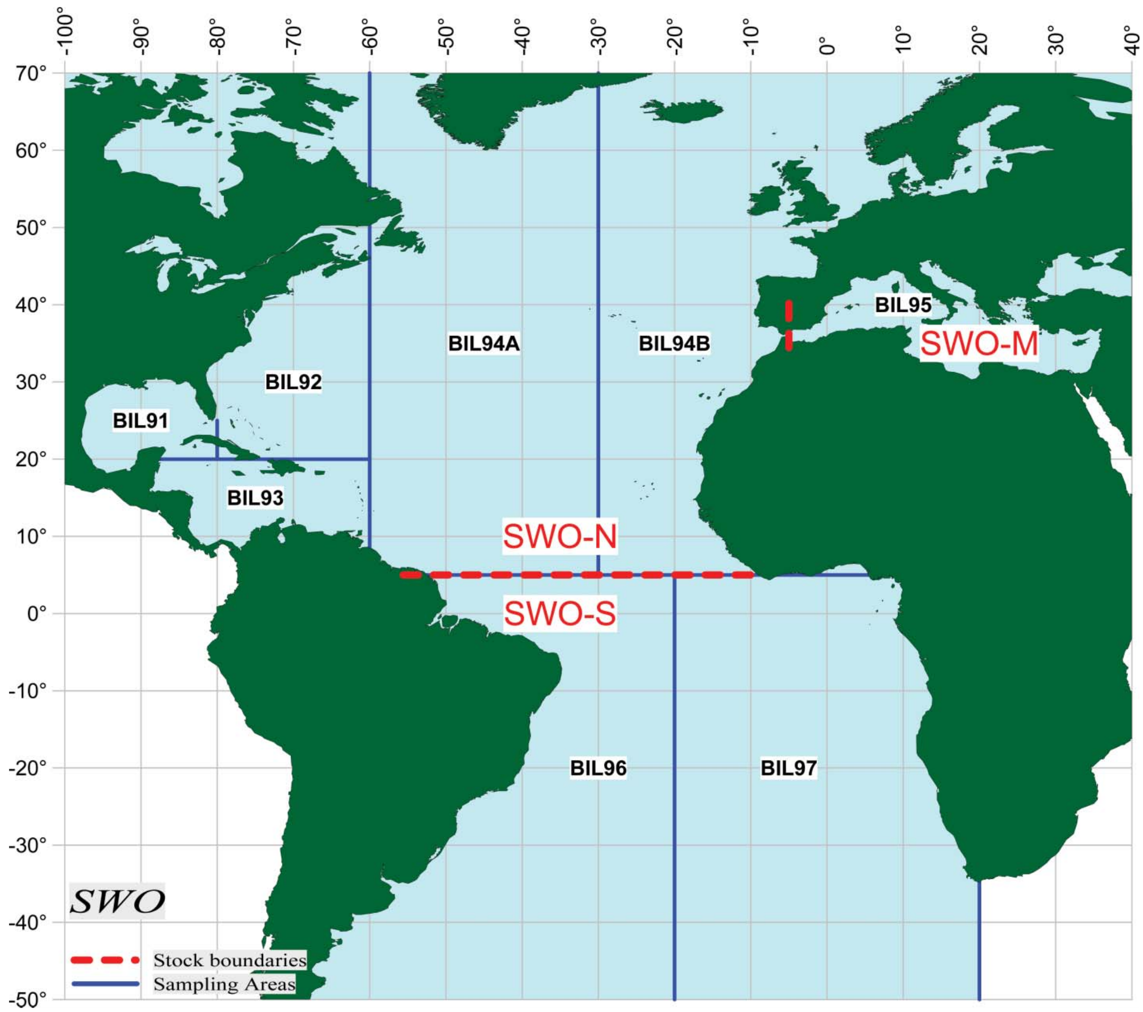

Figure 8 The three management units in the Atlantic recognized by ICCAT. Areas identified by BIL-xxx are regions established for statistical reporting purposes.

west of the 10°W limit currently established by ICCAT (Viñas et al., 2007). Those authors noted one conventionally tagged fish moved from the Mediterranean Sea into the Northeast Atlantic, in the vicinity of Gibraltar.

Interpretations of stock structure based on genetic analyses are not always straight-forward, and can be complicated by low levels of genetic population differentiation (Ward, 2000). Evidence supporting alternative hypotheses of swordfish stock structure can be obtained from examination of conventional tagging results that indicate that trans-Atlantic movements are rare. The infrequency of such movements appears inconsistent with the hypothesis of a single North Atlantic stock (Sperling et al., 2005). However, there are well-recognized limitations associated with conventional tagging that include low and variable rates of detection and return (see review by Guy et al., 1996), and the often non-uniform distribution of effort that can complicate inferences of migration (Armannsson et al., 2007).

The advent of pop-up satellite archival tag (PSAT) technology has provided a new method to obtain critical information on fish movements and migrations that is independent of the commercial fishery, and not subject to the usual limitations associated with conventional tags (Arnold and Dewar, 2001). Based on the release of 25 PSATs on swordfish off Georges Bank (northwest Atlantic) in 2005 and 2006, Neilson et al. (2009) obtained results that appeared inconsistent with the current stock model that predicts that fish should move freely throughout the North Atlantic. Those authors found that the tracks of these tagged swordfish did not extend further east than 55°W longitude, remaining well within the western half of the North Atlantic (Figure 9). The results also demonstrate a consistent pattern of movement with residence in temperate waters from June to October, followed by migration to the south into the Caribbean Sea, with fish remaining there until April. Those authors recognized that the sample size was small and the releases limited to harpoon-caught individuals in a single location. However, subsequent studies by those same investigators continued, with a further 20 releases on Georges Bank in 2007, followed by 9, 24, and 7 releases off the southern Grand Banks of Newfoundland in 2008 to 2010, respectively. In all cases, the tracks of the released swordfish remained within the northwest

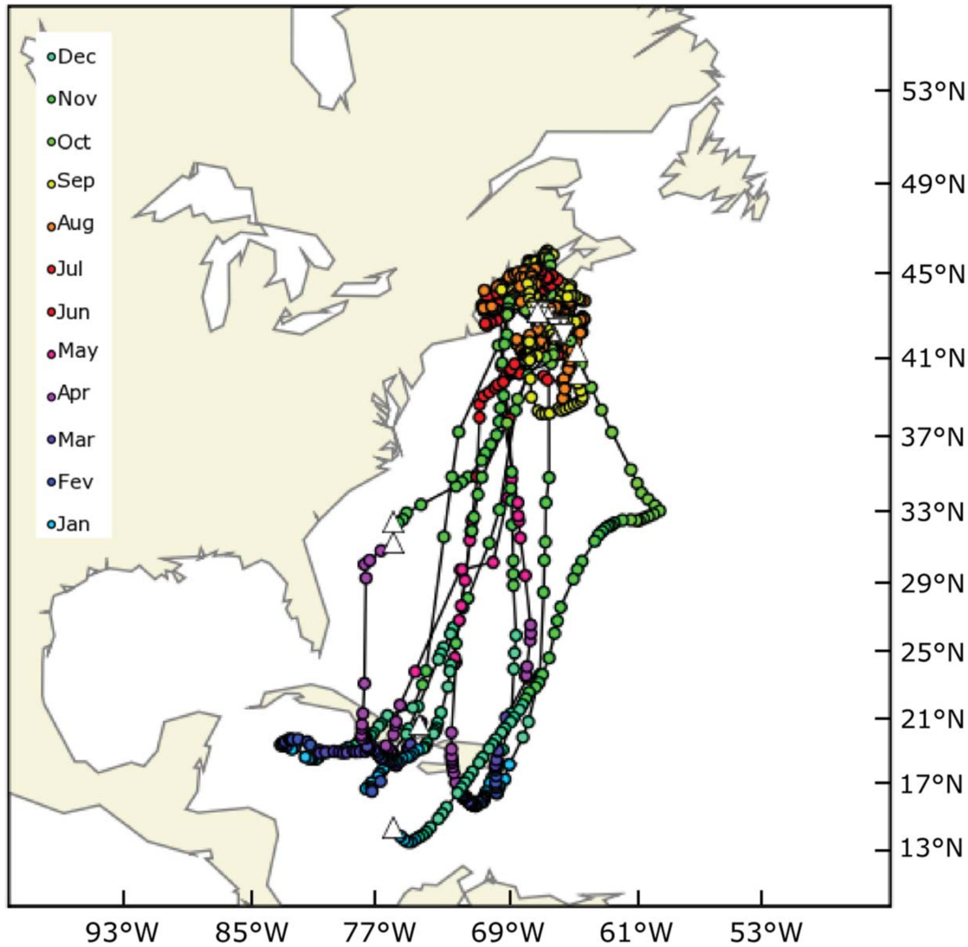

Figure 9 Synoptic map of swordfish tracks (from Neilson et al., 2009), inferred from PSATs deployed in 2005 and 2006, color-coded by month. The symbol ∇ denotes the point of release and Δ denotes the pop-up location and the location of the first transmission for each tagged swordfish.

Atlantic (J. Neilson, Department of Fisheries and Oceans, personal communication, June 2012). PSAT studies have also revealed that swordfish show fidelity to feeding areas in the northwest Atlantic, with long-term deployments often returning to the area where they were originally tagged and released. An example of this precise homing to foraging area can be found in Figure 10 and a similar effect was also observed from conventional tagging in the 1990s, with one individual released and recaptured in the same area on Georges Bank one year later (Stone, 2000). However, other PSAT studies initiated in 2008 on pop-up tagged swordfish released in the central and eastern Atlantic provide evidence of some degree of mixing between the central, western and eastern areas of the North Atlantic (J. Mejuto, personal communication, June 2012). It may be that these PSAT studies that superficially appear contradictory, are indicative of a more spatially complex population structure than was previously understood. Mixing in the spawning areas, however, might also occur more broadly than on feeding grounds, promoting greater homogeneity than one might infer based on tag trajectories placed on fish in opposite sides of the Atlantic.

3 HISTORY OF MANAGEMENT ACTIONS

3.1 ICCAT Management Actions for the North Atlantic Stock

A brief summary of the history of ICCAT management actions is provided in this section. A detailed description can be found in Table 2 and the information is also presented graphically in Figure 11.

Active management of the north Atlantic stock commenced in 1990, when the Standing Committee on Research and Statistics (SCRS) determined that the recent yield of swordfish was not sustainable and that overfishing was occurring and that the mortality of juvenile swordfish exceeded acceptable limits. This was due to increasing catches focused on immature swordfish, which had the joint effect of lowering both MSY and the fishing effort needed to produce MSY. To reduce fishing mortality on Atlantic swordfish, ICCAT recommended a variety of measures including effort restrictions, a 125 cm LJFL minimum size limit (with 15% allowance for incidental catches), and the implementation of additional

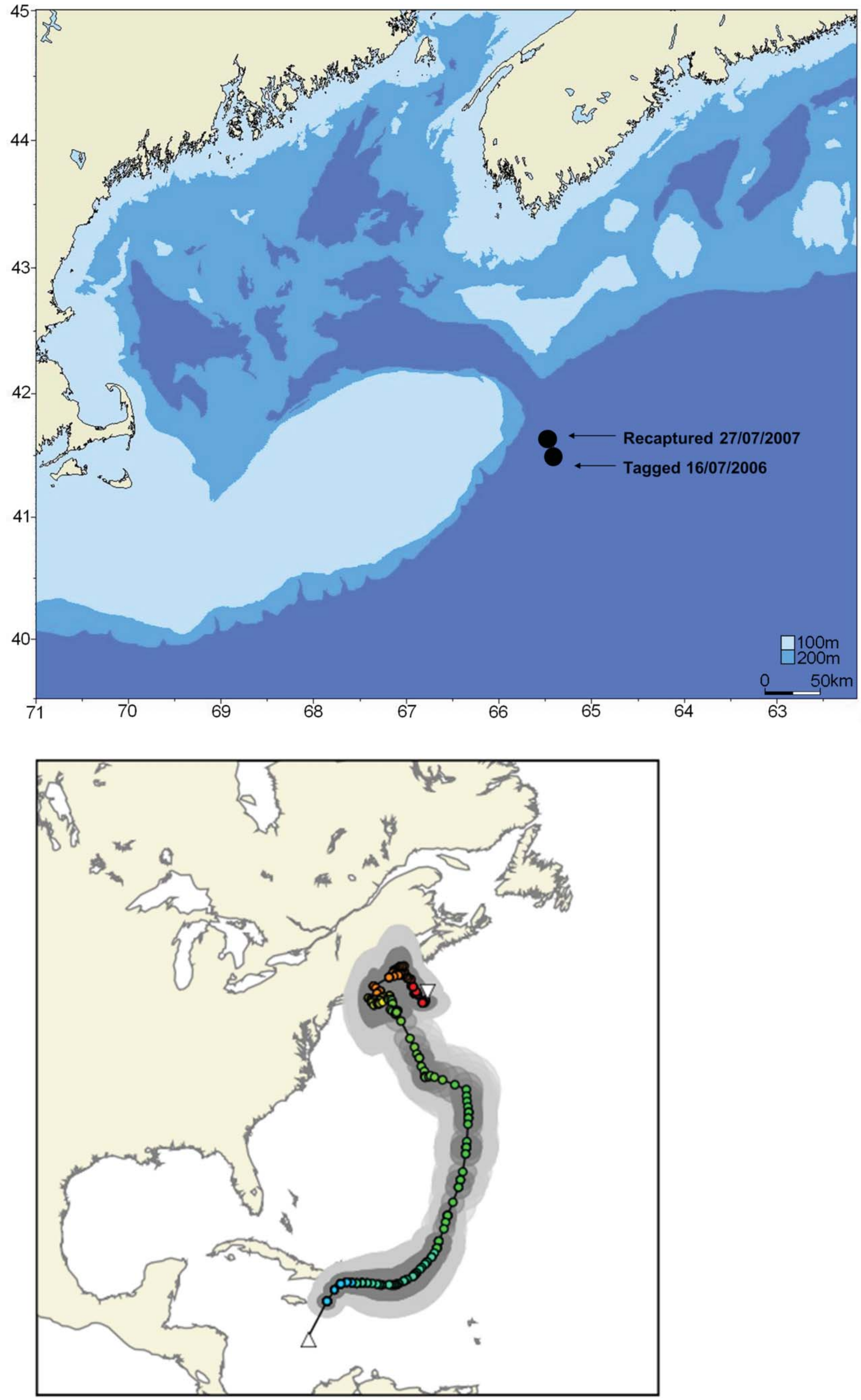

Figure 10 Example of precise homing of swordfish to foraging grounds in the North Atlantic. As shown on the top panel, a pop-up satellite archival tag released off Georges Bank in the northwest reported January 4, 2007 from the Caribbean Sea, about five months after release. However, the fish retained its conventional Floy tag, and the location of recapture was within a few kilometers of its release point one year later.

Table 2 A history of stock status and management measures for north Atlantic swordfish (NATL-SWO)

Year	ICCAT regulation	Stock status	Management measures
1990	Rec. 90-02	Both overfished and undergoing overfishing	ICCAT recommended that F or Effort be capped such that catches would not exceed the 1988 level; CPCs targeting NATL-SWO should reduce F on individuals larger than 25 kg by 15%; Minimum size limit of 125 cm LJFL or 25 kg live weight with 15% tolerance for incidental catches; CPCs not targeting swordfish should implement measures to restrict incidental catches to no more than 10% of the total weight of the entire catch. CPCs also encouraged to employ other suitable measures to protect small swordfish.
1994	Rec. 94-14	Both overfished and undergoing overfishing	ICCAT recommended national quotas for directed fleets during 1995–96; Japanese incidental catch of NATL-SWO limited to 8% of its total catch during 1995–1996; incidental catches of other CPCs not to exceed 1993 level during same period.
1995	Res. 95-09	Overfished: Biomass = 68% of B_{msy}	ICCAT resolved that the SCRS would develop TAC series that allowed a 50% probability of rebuilding to the level of biomass that corresponds to MSY within 5, 10, and 15 years.
1995	Rec. 95-10	Overfished: Biomass = 68% of B_{msy}	ICCAT recommended that CPCs could elect to use the lower minimum size to prohibit the taking, landing and sale of swordfish and swordfish parts less than 119 cm LJFL, or the equivalent in weight, without tolerance. ICCAT also stipulated that any CPC which elected the lower size limit use suitable practices to record discards, and reiterated its recommendation that CPCs continue to implement other measures to protect small swordfish.
1995	Rec. 95-11	Overfished: Biomass = 68% of B_{msy}	ICCAT recommended% TAC shares based upon recent landings. Beginning in 1997, and until otherwise agreed, the percentage shares of the TAC of NATL-SWO would be as follows: Canada 10%, Japan 6.25%, Portugal 7.5%, Spain 41.25%, United States 29%, others 6%. ICCAT also made provisions for national catch quota overages and underages.
1995	Rec. 95-13	Overfished: Biomass = 68% of B_{msy}	ICCAT resolved to promote compliance by non-CPCs and conduct, through an appropriate subsidiary body, an annual review of each CPC and non-CPCs implementation of conservation recommendations and if necessary, recommend new measures to ensure compliance with conservation objectives.
1996	Rec. 96-07	Both overfished (B = 58% of B_{msy}) and undergoing overfishing (F = 204% of F_{msy})	ICCAT set TACs for NATL-SWO at 11,300 mt in 1997, 11,000 mt in 1998 and 10,700 mt in 1999. Percentage shares were set according to Rec. 95–11. ICCAT also recommended that 1) all nations that harvest NATL-SWO should provide annual reports of catch, effort, and catch at size, by sex when possible and 2) that the SCRS review these data annually. Recommendations regarding the minimum size limit remained in place. ICCAT also adjusted the methods used to adjust annual catch quotas for overages and underages.
1996	Rec. 96-14	See above	CPCs exceeding the catch limit during the previous fishing year were directed to report to the compliance committee to explain the overage and measures taken or in progress to avoid future overages. In addition, the CPCs catch limit during the subsequent management period would be reduced by 100% of the amount of the overage. Other "appropriate actions" were also permissible at the discretion of ICCAT. Finally, if CPC's exceeded the catch limit during two consecutive management periods, ICCAT recommended measures including, but not limited to, reduction in the catch limit by a minimum of 125% of the overage and possible import restrictions.
1997	Rec. 97-06	See above	To prevent the untimely development of formerly small and/or incidental fisheries, ICCAT recommended that those entities without a specific quota reduce their catches during 1998–1999 by 45% of their 1996 catch levels. An exception was granted to those entities whose 1996 catch was below 100 mt, they were directed not to increase their catches above the 1996 level.
1998	Res. 98-17	See above	ICCAT directed CPCs, non-CPCs and other fishing entities to provide the SCRS with the best available Task I, Task II, catch at size, discard mortality and CPUE data to support the 1998 stock assessment. They also requested that research be conducted to clarify stock structure and assist assignment of catches to the area of natal origin.
1999	Rec. 99-02	Improving but overfished (B = 65% of B_{msy}) and undergoing overfishing (F = 134% of F_{msy}). Evidence of strong recruitment in 1997–98.	ICCAT re-emphasized their commitment to achieve, with at least 50% probability, rebuilding to the biomass levels associated with MSY within 10 years. To that end ICCAT set annual TACs at 10,600 mt in 2000, 10,500 mt in 2001 and 10,400 mt in 2002. The allocation of TAC was inclusive of a dead discard allowance. If a CPCs dead discards exceeded their allowance, they were required to deduct the amount in excess from their allocation of retained catch in the following year. All other non-conflicting management regulations remained in force.
1999	Res. 99-03	See above	ICCAT directed CPCs, non-CPCs and other entities to support national and international research programs to elucidate the structure, mixing and boundaries of the swordfish stocks and advised that the results of these studies be considered during the next SCRS stock assessment.
1999	Res. 99-04	See above	ICCAT resolved that the SCRS should identify appropriate time/area closures that would protect undersized swordfish stocks in the Atlantic Ocean. To enable that effort, ICCAT required CPCs, non-CPCs and other entities provide data on catch at size, by sex, location, and month of capture on the smallest scale possible. ICCAT also tasked the SCRS to conduct studies to determine whether longline gear modifications could reduce catches of undersized swordfish.

Table 2 A history of stock status and management measures for north Atlantic swordfish (NATL-SWO) *(Continued)*

Year	ICCAT regulation	Stock status	Management measures
2000	Rec. 00-03	See above	Given certain stipulations, ICCAT allowed Japan to count 400 mt of its 2001 NATL-SWO catch against the uncaught U.S. swordfish quota. Japan was also allowed to count 400 mt of its 2002 NATL-SWO catch against its uncaught South Atlantic quota. In return, Japan was directed to conduct research to significantly improve the understanding of stock structure and mixing, to implement a national observer program and to submit catch and discard data from this program to the SCRS for a complete review.
2001	Rec. 01-04	See above	ICCAT reiterated the need to reduce fishing mortality on juvenile swordfish though a variety of approaches including time-area closures and gear modifications.
2002	Rec. 02-02	Improving, somewhat overfished (B = 95% of B_{msy}) but no longer undergoing overfishing (F = 75% of F_{msy}). Additional years of strong recruitment noted.	ICCAT set a TAC of 14,000 mt for the years 2003–2005. A dead discard allowance on 100 mt was designated in 2003, to be deducted from the TAC. After 2003, the TAC was intended to include any dead discards. Allocation of the TAC was redefined as follows: European community 52.42%, United States 30.49%, Canada 10.52%, Japan 6.57%, other CPCs and others 8.46%. ICCAT also adjusted to method used to adjust annual quotas for overages and underages. ICCAT allowed Japan to continue to count 400 mt of its North Atlantic swordfish catch against its uncaught South Atlantic quota. However, ICCAT continued to recommend that Japan implement an observer program by the end of 2005 with at least 8% vessel coverage, and that catch and discard data be submitted to ICCAT and reviewed by the SCRS. Other non-conflicting management measures remained in force.
2002	Res. 02-04	See above	Therefore, ICCAT re-emphasized the need for ongoing evaluation of the mortality of small swordfish, stock dynamics and changes in fishing activities due the new management measures.
2003	Rec. 03-04	See above	ICCAT revised the assessment schedule for NATL-SWO. The next assessment would occur in 2006, and thereafter every three years.
2004	Rec. 04-02	See above	Due to the postponement of the 2005 assessment, Rec. 04-02 revised the rebuilding program described in Rec. 02-02 to extend the existing management measures through 2006. All other measures remained unchanged.
2006	Rec. 06-02	Nearly recovered. B near B_{msy}; $F < F_{msy}$ since 2001	ICCAT adopted a supplemental recommendation to amend the previous rebuilding program, extending the 14,000 mt TAC through 2008 and elected to add 2,690 mt, the unused portion of the United States quota during 2003–2006, to the TACs during the new management period. This addition brought the recommended TAC to levels that exceeded the scientific recommendations. Some changes were made to the treatment of overages and underages. ICCAT also continued to allow Japan to count 400 mt of its North Atlantic swordfish catch against its uncaught South Atlantic quota and continued to recommend that Japan implement an observer program. ICCAT also granted CPCs TAC transfer rights in specific cases. Transfer could not be used to cover over-harvests and could not be retransfered. Other non-conflicting management measures remained in force.
2008	Rec. 08-02	See above	This recommendation revised the rebuilding program described in Rec. 06-02 to extend the existing management measures through 2009. All other measures remained unchanged.
2009	Rec. 09-02	Recovery plan achieved with >50% probability. $B > B_{msy}$, $F < F_{msy}$. MSY = 13,730 mt.	ICCAT recommended a TAC intended to maintain the stock at or above Bmsy (TAC in 2010 = 13,700 mt, just below the estimated MSY). If any CPC, non-CPC, or other entitiy exceeded this amount, the excess was to be deducted from their quota on a prorate basis in 2011. In addition, ICCAT authorized some transfer of quotas between the northern and southern stocks (200 mt) and between nations (100 mt). Finally, ICCAT recommended that the SCRS develop a precautionary limit reference point to be applied during the 2012 assessment, and proposed that future management of this stock would trigger a rebuilding plan if the stock biomass approached the limit reference point established by the SCRS.
2010	Rec. 10-02	See above	ICCAT reiterated its desire to maintain the stock at the levels that consistently produce MSY with greater than 50% likelihood. For this purpose, they set the 2011 TAC at 13,700 mt, just below the MSY estimate from the 2009 assessment. If the total catch of 13,700 mt is exceeded in 2011, ICCAT recommended that the excess be deducted from the quotas in 2013. Other non-conflicting recommendations remain in place. ICCAT continues to recommend that Japan institute a national observer program.

CPCs: contracting parties; LJFL: lower jaw fork length; MSY: maximum sustainable yield; TAC: total allowable catch; B: biomass; F: fishing mortality; SCRS: ICCAT Subcommittee on Research and Statistics; CPUE: catch per unit effort; mt: metric tons.

measures to minimize directed and incidental catch of small swordfish throughout the Atlantic Ocean (ICCAT recommendation 90-02[1]).

Nonetheless, in 1994 (ICCAT recommendation 94-14), SCRS advised that the Atlantic swordfish stocks remained overfished and that overfishing was still occurring. In response, ICCAT recommended additional measures to protect swordfish. In particular, the implementation of national quotas for the major directed fleets (e.g., Canada, Portugal, Spain, and the United States), and the introduction of measures intended to restrict large incidental catches and cap the total catch of swordfish at a level that would permit rebuilding of the stock.

[1]All ICCAT management measures may be found at www.iccat.int.en/RecsRegs.asp

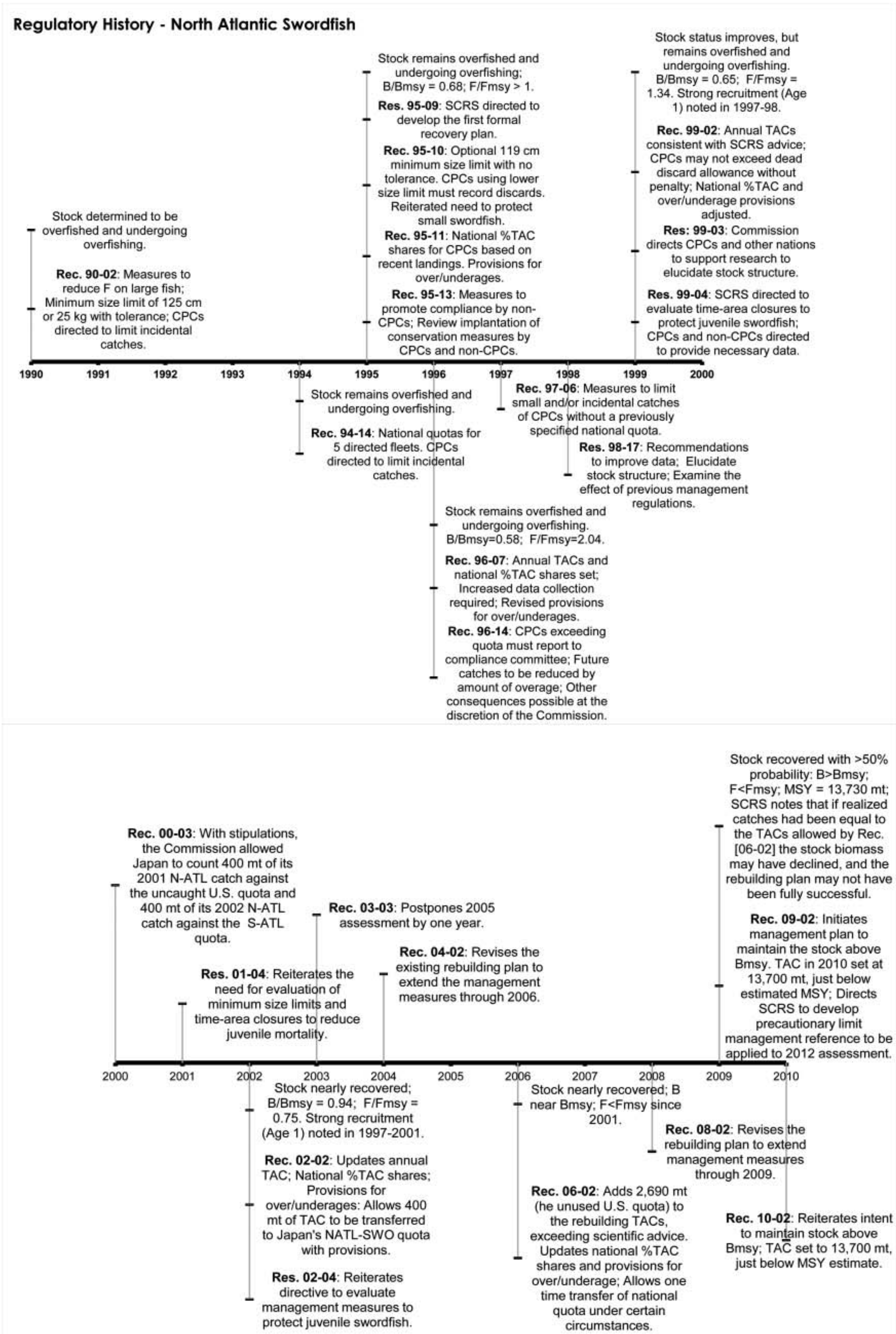

Figure 11 Timeline of stock status and management measures for north Atlantic swordfish). CPCs: contracting parties; MSY: maximum sustainable yield; TAC: total allowable catch; B: biomass; F: fishing mortality; SCRS: ICCAT Subcommittee on Research and Statistics; mt: metric tons.

In 1995 (see ICCAT resolution 95-09), SCRS reevaluated the status of north Atlantic swordfish and reported that biomass in 1994 was only 68% of the level required to produce MSY. In response, ICCAT resolved that SCRS would develop total allowable catch (TAC) series that allowed a 50% probability of rebuilding to the level of biomass that corresponds to MSY within 5, 10, and 15 years, thereby initiating the first formal recovery program for the north Atlantic stock (ICCAT Recommendation 95-10). To facilitate the orderly and equitable setting of TAC shares ICCAT recommended percentage catch shares based upon recent nations landings and made provisions for national quota overages and underages (ICCAT recommendation 95-11).

During 1995, SCRS also evaluated the effectiveness of previous management measures and found that the minimum size regulations (ICCAT recommendation 90-02) intended to reduce the mortality of small swordfish were unproductive due to the allowed 15% tolerance for incidental catches of small swordfish. Therefore, SCRS recommended an alternate lower minimum size limit (119 cm LJFL) be implemented without tolerance. ICCAT considered this advice and recommended that any contracting party could elect to use the lower minimum size without tolerance as long as suitable practices to record discards were employed.

By 1995, ICCAT had implemented numerous management regulations for the north Atlantic swordfish stock. It was recognized that many vessels with directed harvest of north Atlantic swordfish were registered to nations that were not members of ICCAT and, thus, not subject to the management regulations. This diminished the ability of ICCAT to maintain the stock at the levels which permitted harvest of the MSY.

Therefore, in 1995, ICCAT resolved (ICCAT recommendation 95-13) to promote compliance by non-contracting parties by requesting full cooperation with ICCAT conservation programs, by identifying those non-contracting parties whose vessels fished for Atlantic swordfish in a manner inconsistent with current conservation recommendations and by implementing non-discriminatory trade restrictions on Atlantic swordfish products from those non-contracting parties so identified. ICCAT also resolved to conduct, through an appropriate subsidiary body, an annual review of each contracting and non-contracting party's implementation of conservation recommendations and recommend new measures, if necessary, to ensure compliance with conservation objectives.

SCRS completed an updated stock assessment of the north Atlantic swordfish stock in October 1996 (Anon., 1996) and concluded that the stock remained overfished, that overfishing was still ongoing, that current catches were unsustainable, and that catch quotas had been exceeded by some contracting parties. Indeed, the spawning stock biomass was estimated to be 58% of the biomass capable of producing MSY while the fishing mortality rate was 204% of F_{MSY}. These estimates were more unfavorable than the previous assessment, indicating that the decline was worsening and additional management measures were essential. In a strongly worded statement, SCRS advised dramatic reductions in both fishing mortality and catch, and remarked on the need to recognize the "failure of regulatory measures to achieve sufficient reductions in fishing mortality since 1991" (Anon., 1997b, p. 63). SCRS also noted that, given the resilient nature of the stock, immediate and appropriate action could be expected to improve the stock status and allow recovery to convention objectives within 15 years. They strongly advised that annual TACs not exceed 10,000 mt.

In response, ICCAT set TACs for north Atlantic swordfish at 11,300 mt in 1997; 11,000 mt in 1998; and 10,700 mt in 1999 (ICCAT recommendation 96-07).

Recognizing that the north Atlantic swordfish stock remained in an overfished condition in 1996 and that national quotas had been exceeded in some cases, ICCAT also made several recommendations to discourage further overages (ICCAT recommendation 96-14) including, but not limited to, reduction in the catch limit by a minimum of 125% of the overage and possible import restrictions.

Although annual TACs were implemented beginning in 1997, a 6% share of the TAC had been set aside for those contracting parties that did not receive a specific quota. However, it was soon noted that the overall catches by contracting parties lacking a designated quota were increasing while the annual TAC was decreasing.

Given the depressed condition of the stock, and to prevent the untimely development of formerly small and/or incidental fisheries, ICCAT recommended that those entities without a specific quota limit or reduce their catches to 45% of 1996 levels and that entities with no reported catches in 1996 refrain from developing any directed swordfish fishery in the north Atlantic during 1998–1999 (ICCAT recommendation 97-06).

In preparation for the 1999 SCRS assessment of north Atlantic swordfish, ICCAT made a resolution (ICCAT resolution 98-17) to improve data collection and submission, and requested that research be conducted to clarify stock structure and assist assignment of catches to the area of natal origin. ICCAT also instructed SCRS to examine the effectiveness of current regulations, especially those intended to reduce juvenile mortality.

The results of the 1999 SCRS stock assessment of north Atlantic swordfish showed some improvement. In fact, there was evidence that the decline in stock status had been slowed or possibly arrested. Nevertheless, the stock remained overexploited and overfishing continued. As of 1998, the level of biomass was estimated at 65% of the B_{MSY} and fishing mortality was 134% of F_{MSY}. The SCRS noted high recruitments of age-1 fish in 1997 and 1998, which were expected to result in eventual increases in spawning biomass if these year-classes could be protected, but cautioned that the expected landings in 1999 (11,800 mt) would result in a >50% risk of further deterioration in stock status.

ICCAT noted the improvements in catch rates after only two years of strict quota regulations imposed in 1997, and reemphasized their commitment to improve the conservation of small swordfish, account for all sources of fishing mortality in management regulations, and achieve, with at least 50%

probability, rebuilding to the biomass levels associated with MSY within ten years. To that end, ICCAT recommended a ten-year rebuilding program with the goal to achieve B_{MSY}, with greater than 50% probability, beginning in 2000 and continuing through 2009.

To achieve this, ICCAT set the annual TACs at 10,600 mt in 2000; 10,500 mt in 2001; and 10,400 mt in 2000 (ICCAT recommendation 99-02). Thereafter, the TACs would be adjusted according to SCRS advice. The allocation of TAC was inclusive of a dead discard allowance to be deducted from the TAC. ICCAT also recommended that in the year 2002, and every three years thereafter, a stock assessment of north Atlantic swordfish be conducted.

During the 1999 assessment, the SCRS also evaluated the potential for time-area closures to effectively reduce fishing mortality on juvenile swordfish and reported that certain closures could be effective. Consequently, ICCAT resolved (ICCAT resolution 99-04) that the SCRS should identify appropriate time-area closures to protect undersized swordfish stocks. To enable that effort, ICCAT required the submission of data on catch at size, by sex, location, and month of capture on the smallest scale possible. ICCAT also tasked the SCRS to conduct studies to determine whether longline gear modifications could reduce catches of undersized swordfish.

In 2000, it was recognized that the Japanese longline fleet operating in the North Atlantic was likely to exceed its five-year swordfish quota. ICCAT noted that the Japanese had taken steps to reduce the mortality of swordfish bycatch which some countries, primarily the United States, had not caught their entire quota, and that stock structure was poorly understood. For these reasons, ICCAT allowed Japan to count a portion of its 2001 North Atlantic swordfish catch against the uncaught United States swordfish quota and a portion of its 2002 North Atlantic swordfish catch against its uncaught South Atlantic quota. In return, Japan was directed to conduct research to significantly improve the understanding of stock structure and mixing, and to implement a national observer program that conformed to specified requirements (ICCAT recommendation 00–03).

ICCAT also resolved (ICCAT resolution 01-04) that contracting parties, cooperating non-contracting parties, entities, and fishing entities evaluate any long-term time-area closures implemented within the ICCAT convention area and present their evaluations to SCRS for consideration and encouraged RFMO to implement time-area closures if scientific evidence identified an area as important for juvenile swordfish.

In an effort to protect small swordfish and other species caught incidentally by the U.S. longline fleet, the United States implemented five domestic time and area closures in the North Atlantic. These closures reduced the U.S. swordfish catches, and may also have redistributed the fleet. Effects on catch per unit effort were not immediately obvious.

SCRS updated the stock assessment of north Atlantic swordfish in September 2002 (Anon., 2003). The high recruitments noted during the previous assessment were also detected during 1999–2001. It was also reported that high recruitments had now been observed in several fisheries, and manifested across several age classes. Therefore, SCRS concluded that these high recruitments, along with measures mandated by ICCAT, had resulted in an increase in the North Atlantic stock size, and an improvement in stock status. Although the stock was still somewhat overfished (biomass was estimated at 94% of B_{MSY}) overfishing had ceased (F was estimated at 75% of F_{MSY}). Furthermore, SCRS projections indicated that catches of 14,000 mt for 2003–2009 were consistent with ICCAT objective to rebuild the north Atlantic stock by 2009 with a probability of at least 50%.

In response to the new assessment, ICCAT set a TAC of 14,000 mt for the years 2003–05 (ICCAT recommendation 02-02). A dead discard allowance on 100 mt was also designated in 2003, to be deducted from the TAC. After 2003, the TAC was intended to include any dead discards.

ICCAT allowed Japan to continue to count a portion of its North Atlantic swordfish catch against its uncaught South Atlantic quota and continued to recommend that Japan implement an observer program by the end of 2005 with at least 8% vessel coverage.

As of 2002, the northern Atlantic stock was predominantly comprised of young fish (ages 1–4) but strong year classes had not yet fully recruited to the spawning population. Therefore, ICCAT re-emphasized the need for ongoing evaluation of the mortality of small swordfish, stock dynamics, and changes in fishing activities due the new management measures (ICCAT resolution 02-04).

In September 2006, SCRS conducted an updated assessment of north Atlantic swordfish (Anon., 2007b). The result was more optimistic than the 2002 assessment and supported the conclusion that the stock was almost fully recovered to the level capable of supporting MSY. The estimated trend in relative biomass revealed a consistent increase from 2001–2005 and the 2005 biomass was nearly equal to B_{MSY}. The relative trend in fishing mortality indicated that overfishing had not occurred since 2001, and that current levels were lower than in 2001.

In response, ICCAT adopted a supplemental recommendation to amend the previous rebuilding program, extending the 14,000 mt TAC through 2008. ICCAT also elected to add 2,690 mt (the unused portion of the U.S. quota during 2003–2006) to the TACs during the new management period (ICCAT recommendation 06-02). This addition brought the recommended TAC to levels that exceeded the scientific recommendations.

ICCAT continued to permit Japan to count 400 mt of its North Atlantic swordfish catch against its uncaught South Atlantic quota, and continued to recommend that Japan implement an observer program by the end of 2008 with at least 8% vessel coverage. ICCAT also granted one-time TAC transfer rights in specific cases. Transfer could not be used to cover overharvests and Contracting Parties receiving a one-time quota transfer could not re-transfer that quota.

ICCAT recommendation 08-02 revised the rebuilding program described in recommendation 06-02 to extend the existing management measures for one year (through 2009). All other measures remained unchanged.

The most recent SCRS stock assessment of north Atlantic swordfish was completed in September 2009 (Anon., 2010). According to this assessment, the estimated relative biomass trajectory has shown a consistent increase since 2000, and in 2009, the estimated biomass was just above B_{MSY}. The trajectory of relative fishing mortality indicates that the highest levels of fishing mortality occurred in 1995, and that fishing mortality has been below F_{MSY} since then. These results support the conclusion that, in 2009, there was a greater than 50% probability that the stock of north Atlantic swordfish was at or above the biomass level that could produce MSY, and thus ICCAT rebuilding objective (Recommendation 99-02) had been achieved.

SCRS projections indicated that catches less than 14,000 mt had a 50% chance of maintaining the stock at levels at or above B_{MSY} through 2019. However, to better account for scientific uncertainty, SCRS recommended a more precautionary TAC of 13,000 mt which corresponded to a 75% probability of maintaining the stock at the convention objective through 2019. Maximum sustainable yield was estimated at 13,730 mt.

In the assessment report (Anon., 2010), SCRS also noted that the stock was successfully rebuilt despite the TAC levels established in recommendation 06-02 and recommendation 08-02, which exceeded scientific recommendations by 12%, but which were not realized. SCRS cautioned that if the realized catches had been equal to the TACs allowed by recommendation 06-02 the stock biomass would likely have declined, and the rebuilding plan would not have been fully successful.

Based on the 2009 ICCAT recommendation 09-02, ICCAT recommended a management program for north Atlantic swordfish intended to maintain the stock at or above B_{MSY}. To that end, ICCAT recommended a TAC in 2010 of 13,700 mt (just below the estimated MSY). The B_{MSY} commission also recommended that the SCRS develop a precautionary limit reference point to be applied during the next assessment, and proposed that future management of this stock would trigger a rebuilding plan if the stock biomass approached the limit reference point established by the SCRS.

The most recent management plan for north Atlantic swordfish reiterates ICCAT's desire to maintain the stock at the levels that consistently produce MSY, with greater than 50% likelihood. For this purpose, they set the 2011 TAC at 13,700 mt, just below the MSY estimate from the 2009 assessment (ICCAT recommendation 10-02). National catch limits, and authorized transfers of quota are described therein. If the total catch of 13,700 mt is exceeded in 2011, ICCAT recommended that the excess be deducted from the quotas in 2013.

3.2 ICCAT Management Actions for the South Atlantic Stock

A summary of the history of ICCAT management actions is provided in this section. This information is also presented graphically in Figure 12. Details of the management actions are also provided in Table 3.

From 1960 to 1979, swordfish catches remained below 5,000 mt, with an average of 2,500 mt. The increase of swordfish landings in the South Atlantic Ocean started in 1980, due to progressive shifts of fishing effort to the South Atlantic, mainly from the North Atlantic, where fisheries targeting swordfish have operated since the early 1960s, as well as other waters (Anon., 2011). The development of fishing activities by southern coastal countries (national fleets and charter arrangement) also contributed to the increase in catches. Thus, from 1980 to 1995, when landings reached a peak of 21,930 mt, catches showed an increase of 412% in the South Atlantic Ocean. After this peak, a gradual decrease in catches has been observed. In 2011, the 12,566 mt of reported catches were about 43% lower than the 1995 reported level.

Considering the historical trend of catch, as well as management actions implemented by ICCAT described below, we can consider that, at least partially, this reduction in swordfish catch in the South Atlantic, following the peak in 1995, resulted from regulations.

Although management measures applied directly to the South Atlantic stock of swordfish have been implemented only since 1994, measures for the entire Atlantic Ocean entered into force in 1990 (recommendation 90-02). In that year, the Commission adopted measures to protect juvenile swordfish, including the prohibition of the capture and landing of small swordfish throughout the Atlantic Ocean. Thus, a minimum weight limit of 25 kg live weight or a minimum size limit of 125 cm LJFL, with an allowable 15% tolerance for incidental catches, was adopted. In this same recommendation, ICCAT also encouraged Contracting Parties to take other appropriate measures to protect small swordfish, including the establishment of time and area closures.

Concerned about a significant increase in catches and a decline of some catch per unit effort (CPUE) series, ICCAT recommended specific measures in 1994 to protect the South Atlantic stock, establishing that:

- Contracting parties whose catches in the south Atlantic were greater than 250 mt should not increase their catches in 1995 and 1996 above their 1993 or 1994 level, whichever was higher.
- Contracting parties whose catches in the south Atlantic were less than 250 mt should not increase their catches above this value in 1995 and 1996 (ICCAT recommendation 94-14). Despite the adoption of these measures, swordfish catches continued to increase significantly, reaching a peak of 21,930 mt in 1995.

In 1996, the first stock assessment of South Atlantic swordfish was carried out (Anon., 1996), and indicated that the levels of harvest at that time were not sustainable. Despite the preliminary nature of this stock assessment analysis, SCRS concluded that the stock was near the biomass associated with MSY

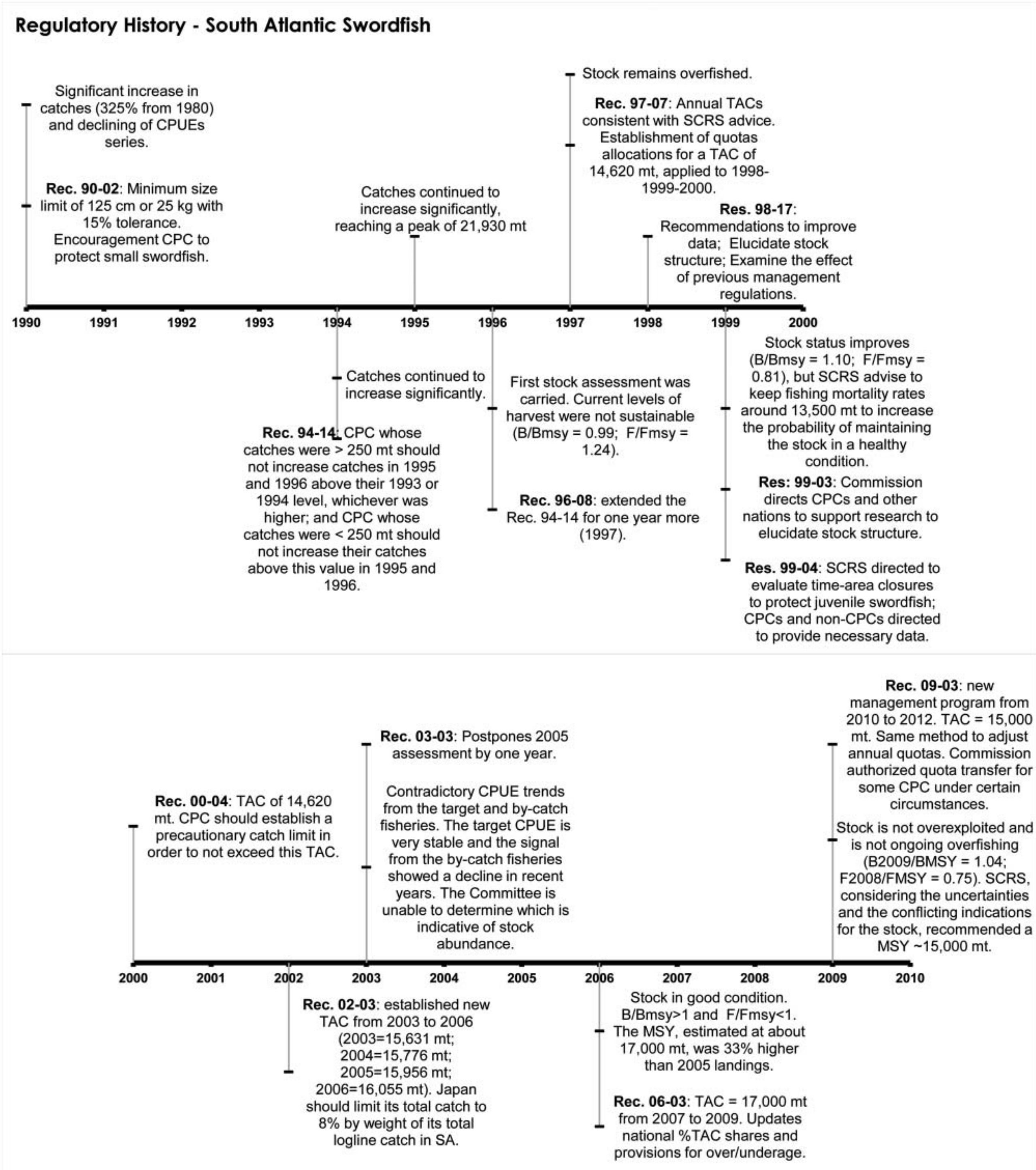

Figure 12 Timeline of stock status and management measures for south Atlantic swordfish). CPCs: contracting parties; MSY: maximum sustainable yield; TAC: total allowable catch; B: biomass; F: fishing mortality; SCRS: ICCAT Subcommittee on Research and Statistics; mt: metric tons.

($B_{1966} = 0.99 * B_{MSY}$), but the fishing mortality rate was about 24% higher than the corresponding optimal level ($F_{1995} = 1.24 * F_{MSY}$). To rebuild and maintain the stock at biomass levels that could support MSY, SCRS proposed the adoption of measures to reduce fishing mortality substantially to around 13,000 mt or less in 1997 and thereafter.

In response, ICCAT adopted recommendation 96-08 in order to extend recommendation 94-14 for an additional year

Table 3 Timeline of stock status and management measures for South Atlantic swordfish (SATL-SWO)

Year	ICCAT regulation	Stock status	Management measures
1990	Rec. 90-02	Significant increase in catches (325% from 1980) and declining of CPUEs series.	Minimum size limit of 125 cm LJFL or 25 kg live weight with 15% tolerance for incidental catches; CPCs also encouraged to employ other suitable measures to protect small swordfish. The CPCs that target directly fishing for swordfish shall take the necessary measures to limit the fishing mortality of swordfish in the entire Atlantic Ocean to the level of catch in 1988, or will limit the fishing effort that will result in the equivalent level of fishing mortality.
1994	Rec. 94-14	Catches continued to increase significantly.	CPCs whose catches were greater than 250 mt should not increase their catches during 1995 and 1996 beyond their 1993 or 1994 level, whichever is higher. CPC whose catches were less than 250 mt should not increase their catch in 1995 and 1996 beyond 250 mt. CPCs also encouraged to take other appropriate measures to protect small swordfish
1996	Rec. 96-08	Currente levels of harvest were not sustainable ($B = 99\%$ of B_{msy}; $F = 125\%$ of F_{msy})	CPCs whose catches were greater than 250 mt shall not increase their catches during 1997 beyond their 1993 or 1994 level, whichever is the higher. CPCs whose catches were less than 250 mt shall not increase their catch in 1997 beyond 250 mt. Recommendations regarding the minimum size limit remained in place.
1997	Rec. 97-07	Stock remains overfished.	Allocation scheme was established for the period 1998–2000. TAC of 14,620 mt.
1998	Res. 98-17	Stock over exploited.	ICCAT directed CPCs, non-CPCs and other fishing entities to provide the SCRS with the best available Task I, Task II, catch at size, discard mortality and CPUE data to support the 1998 stock assessment.
1999	Res. 99-03	Stock status improves ($B/B_{msy} = 1.10$; $F/F_{msy} = 0.81$)	ICCAT directed CPCs, non-CPCs and other entities to support national and international research programs to elucidate the structure, mixing and boundaries of the swordfish stocks and advised that the results of these studies be considered during the next SCRS stock assessment.
1999	Res. 99-04		ICCAT resolved that the SCRS should identify appropriate time/area closures that would protect undersized swordfish stocks in the Atlantic Ocean. To enable that effort, ICCAT required CPCs, non-CPCs and other entities provide data on catch at size, by sex, location, and month of capture on the smallest scale possible. ICCAT also tasked the SCRS to conduct studies to determine whether longline gear modifications could reduce catches of undersized swordfish.
2000	Rec. 00-04	See above	TAC of 14,620 mt in 2001. CPCs, non-CPCs and other entities should establish a precautionary catch limit for 2001, being encouraged to set the catch limit such that the target for the TAC is not exceeded, and should notify the Secretariat of the specified catch limit by the end of 2000.
2002	Rec. 02-03	Contradictory CPUE trends from the target and by-catch fisheries. The committee is unable to determine which is indicative of stock abundance.	ICCAT set a TAC for 2003, 2004, 2005, and 2006 (15,631 mt; 15,776 mt; 15,956 mt; and 16,055 mt, respectively). The TAC and the catch limits for 2006 should be reviewed and if necessary, revised based upon the results of stock assessment to be conducted in 2005. Japan should limit its swordfish catch to 8% by weight of its total longline catch. When the Japanese catch 1,500 mt in one year, ICCAT should consider a different appropriate catch limit. ICCAT allowed Japan to continue to count 400 mt of its North Atlantic swordfish catch against its uncaught South Atlantic quota.
2003	Rec. 03-03	See above	ICCAT revised the assessment schedule for SATL-SWO. The next assessment would occur in 2006.
2006	Rec. 06-03	Stock in good condition. $B/B_{msy} > 1$ and $F/F_{msy} < 1$. The MSY, estimated at about 17,000 mt.	ICCAT set a TAC of 17,000 mt for 2007, 2008, and 2009. ICCAT also adjusted the methods used to adjust annual catch quotas for overages and underages. The maximum underage that a party may carryover in any given year shall not exceed 50% of the quota of previous year. ICCAT allowed Japan to continue to count 400 mt of its North Atlantic swordfish catch against its uncaught South Atlantic quota.
2009	Rec. 09-03	Stock is not overexploited and is not undergoing overfishing. Production models indicated that $B2009/B_{msy} = 1.04$ and $F2008/F_{msy} = 0.75$. Catch only model results indicated that $P(F2008/F_{msy} < 1) = 0.77$ and $P(B2009/B_{msy} > 1) = 0.82$.	ICCAT set a TAC of 15,000 mt for 2010, 2011, and 2012. ICCAT maintained the methods used to adjust annual catch quotas for overages and underages. The maximum underage that a party may carryover in any given year shall not exceed 50% of the quota of previous year. ICCAT authorized some transfer of quotas between the northern and southern stocks (600 mt) and between nations (200 mt).

CPCs : contracting parties; MSY : maximum sustainable yield; TAC : total allowable catch; B : biomass; F : fishing mortality; SCRS : ICCAT Subcommittee on Research and Statistics; CPUE : catch per unit effort; mt : metric tons.

(1997). Due to the important catches of non-member nations, ICCAT recommended that the ICCAT executive secretary request non-contracting parties fishing for swordfish within the ICCAT convention area to cooperate with the implementation of management measures established by ICCAT. In addition, ICCAT proposed an intersessional meeting be held in 1997 to discuss additional measures to protect the South Atlantic swordfish stock, in particular concerning the implementation of an allocation scheme with national quotas.

In 1997, SCRS continued to report their concern about the stock status of south Atlantic swordfish based on the last stock assessment, declining CPUE in some fisheries, and the high levels of catches (over 18,000 mt) in the last three years. In this context, SCRS advised that the south Atlantic swordfish stocks remained overexploited and requested the adoption of management measures as soon as possible to reduce the harvest level below the estimated replacement yield of 14,620 mt in 1996 to keep the stock in a healthy condition.

Based on SCRS advice and aware of the urgent need to implement measures to prevent overfishing of the stock, ICCAT adopted the ICCAT recommendation 97-07 in 1997, that set a scheme of annual quota allocations for the South Atlantic swordfish fishery for 1998, 1999, and 2000. An annual TAC of 14,620 mt was established for each year of the sharing arrangement.

ICCAT also established that the TAC for the year 2000 would be revised at the 1999 meeting, based on the results of the 1999 stock assessment for South Atlantic swordfish. Finally, ICCAT recommended that contracting parties and others need to adopt measures to limit fishing effort and control catches necessary to ensure compliance with the quotas established in this recommendation.

To ensure the necessary support for the 1999 stock assessment, ICCAT approved the resolution 98–17, encouraging contracting parties, non-contracting parties, entities, and fishing entities to provide SCRS with the best available catch, catch at size, discard mortality, and CPUE data. Concerning the results of this stock assessment, ICCAT asked SCRS to develop rebuilding scenarios "that would support MSY with a probability of greater than 50%, within time periods of 5, 10, and 15 years and/or other appropriate times" (resolution 98-17, p. 2), clarifying the discards estimates included in its assessment and projections. ICCAT also requested the SCRS to evaluate the effectiveness of current regulations, especially the management measure to reduce juvenile mortality.

Despite declining catches observed since the last assessment, SCRS continued to be concerned about the swordfish stock status in the South Atlantic. The results of the 1999 stock assessment showed that the level of biomass was close to B_{MSY}. However, if the catch levels for the next ten years were close to the catch limit of 14,620 mt, a biomass decline below the level needed to support MSY was predicted. SCRS emphasized the high levels of uncertainty in the input data used in assessment and recommended to ICCAT to keep fishing mortality rates around 1998 levels ($\sim$13,500 mt) to increase the probability of maintaining the stock in a healthy condition.

Despite the proposal to reduce the TAC to the MSY level of 13,650 mt, ICCAT decided to maintain the sharing allocation and TAC established in the ICCAT recommendation 97-07, which would be renegotiated during its 2000 meeting. However, with the objective of reducing fishing mortality on juvenile swordfish, ICCAT approved the resolution 99-04, requiring the SCRS to analyze and identify times and areas for possible closure to protect undersized North and South Atlantic swordfish. In order to support this task, ICCAT required contracting parties, non-contracting parties, entities, and fishing entities to provide data on catch at size, by sex, location, and month of capture on the smallest scale possible as determined by SCRS.

ICCAT also required SCRS to conduct studies to analyze whether modifications in longline gear configurations could reduce catches of undersized swordfish, and requested that the results be presented at ICCAT meeting in 2002. Based on the uncertainties concerning the boundaries between the northern and the southern stocks and on the recommendation of SCRS to reduce these uncertainties, ICCAT approved the resolution 99-03 resolving that contracting parties, non-contracting parties, entities, or fishing entities should support national and international research programs to reduce these uncertainties, based on genetic analyses, tag-recapture studies and other techniques scientifically appropriate for this goal. The results of these programs were to be considered in the next swordfish assessment.

In 2000, the last year of the sharing arrangement and TAC for South Atlantic swordfish (recommendation 97-07), ICCAT established that in 2001 the TAC for South Atlantic swordfish would be 14,620 mt (recommendation 00-04). Contracting Party, co-operating non-contracting party, entity, and fishing entity that are fishing for South Atlantic swordfish should establish a precautionary catch limit in order to not exceed this TAC, notifying the secretariat of the specified catch limit by the end of 2000. This decision was made taking into account that the working group on allocation criteria had scheduled a meeting in May 2001 to define quota allocation criteria for adoption by ICCAT. So, at its 2001 meeting, ICCAT could negotiate and adopt a sharing arrangement for the TAC for South Atlantic swordfish.

However, in 2001, no new measure was adopted and the management of the South Atlantic stock in 2002 was conducted based on autonomous quotas, as established the previous year.

In 2002, considering that the total catches had been reduced since 1995, the SCRS recommended that catches should remain at about the same level of the past few years. ICCAT recalled the "Criteria for the Allocation of Fishing Possibilities" (Anon., 2002) and approved Rec. 02-03 to provide an equitable sharing of the South Atlantic swordfish resource over a four-year period (2003 to 2006).

This recommendation also established that the TAC and the catch limits for 2006 should be reviewed and, if necessary, revised based on the results of the stock assessment to be conducted in 2005. In this case, the relative shares of the parties for 2006 should remain unchanged from those in the current recommendation. ICCAT recommended that Japan limit its total catch of southern swordfish to 8% by weight of its total longline catch in the South Atlantic Ocean. ICCAT allowed Japan to count 400 mt of its North Atlantic swordfish catch taken from the management area located to the east of 35°W and south of 15°N, against its uncaught South Atlantic quota.

In 2003, ICCAT approved the ICCAT recommendation 03-03 to amend the ICCAT recommendation 02-03 on south Atlantic swordfish catch limits, to postpone the 2005 stock assessment to 2006.

In September 2006, SCRS conducted an updated assessment of south Atlantic swordfish (Anon., 2007b) and noted an improvement in the information level available from fisheries harvesting the species in this part of Atlantic Ocean. The results obtained indicated that the stock was in good condition. The fishing mortality rate was below that which would produce MSY, and the biomass above that which would result from fishing at F_{MSY} in the long term. The MSY, estimated at about 17,000 mt, was 33% higher than 2005 landings.

In response, ICCAT approved the ICCAT recommendation 06-03, establishing a new TAC of 17,000 mt and catch limits for the period 2007, 2008, and 2009.

A method to adjust annual quotas for overages and underages was also established, defining that overages and underages occurring in a given year (catch year) would be adjusted during or before the adjustment year (until two years after the catch year). The maximum underage that a party could carryover could not exceed 50% of the quota of previous year.

ICCAT continued to permit Japan to count up to 400 mt of its North Atlantic swordfish catch taken from the part of the North Atlantic management area that is east of 35°W and south of 15°N, against its uncaught South Atlantic quota.

In 2009, based on the stock assessment conducted in September, SCRS concluded that more research would be needed to reduce the high uncertainty in stock status for the South Atlantic swordfish stock (Anon., 2010), since the base case production model indicated conflicting signals for several of the indices used. The relative biomass (B/B_{MSY}) trajectory estimated by A Stock Production Model Incorporating Covariates (ASPIC) for the base case for south Atlantic swordfish showed an increasing trend since 2002, and was just above B_{MSY} in 2009 ($B_{2009}/B_{MSY} = 1.04$), indicating that the stock was not overexploited. The trajectory of relative fishing mortality (F/F_{MSY}) indicated that the highest levels of fishing mortality occurred in 1995, then decreased, and were below F_{MSY} in recent years ($F_{2008}/F_{MSY} = 0.75$), indicating that the stock was not being overexploited. Due to the conflicting trends shown by some of the standardized CPUE indices available, a catch-only model was used. The results showed a probability of 0.77 that the stock was not overfished and that overfishing was not occurring. SCRS, considering the uncertainties and the conflicting indications for the stock, recommended that the annual catch should not exceed the estimated MSY (~ 15,000 mt). SCRS advice was upheld by ICCAT who approved recommendation 09-03, establishing a new management program for south Atlantic swordfish for the period 2007, 2008, and 2009, and an annual TAC of 15,000 mt.

The same method to adjust annual quotas was established. The overages and underages occurring in a given year (catch year) would be adjusted during or before the adjustment year (until two years after the catch year). The maximum underage that a party may carryover shall not exceed 50% of the quota of previous year.

ICCAT continues to allow Japan to count up 400 mt of its North Atlantic swordfish catch taken from the part of the North Atlantic management area that is east of 35°W and south of 15°N, against its uncaught South Atlantic quota. ICCAT authorized the European community to count up to 200 mt of its swordfish catch taken from the North Atlantic management area against its uncaught south Atlantic swordfish quota.

In addition, ICCAT authorized quota transfers from South Africa, Japan, and the United States to Namibia (50 mt × 3 = a total of 150 mt); from United States to Côte d'Ivoire (25 mt); and from United States to Belize (25 mt). The quota transfers shall be reviewed annually in response to a request from an involved CPC (contracting and co-operating non-contracting party).

3.3 The Stock Responses to Management Measures

Whether due to chance or circumstance, the information available indicates ICCAT management actions have enabled rebuilding of both northern and southern Atlantic swordfish from an overfished condition ($B < B_{MSY}$) to one consistent with the objective of ICCAT convention. Given the timeline of assessment outcomes, science-based management recommendations, and management actions described previously, it is possible to isolate those actions most likely to have promoted rebuilding. In the northern Atlantic case, the introduction of a minimum size regulation had little, if any, immediate effect on the rate of overfishing and the corresponding rate of depletion of the stock (Figure 13). In contrast, implementation of a constraining TAC in combination with closures of various types, designed to reduce mortality on juvenile fish, and a period of improved recruitment (Figure 7) appeared to result in a rapid reduction in fishing mortality and corresponding increase in biomass of north Atlantic swordfish. Of key importance was the establishment of a rebuilding time-frame and tolerable risk of failure for achieving the convention objective to guide management choices. While it is notable that management agreements regarding TAC frequently exceeded the scientific advice in order to achieve the consensus among parties needed to adopt the management agreements, realized catches generally did not reach the TAC (Figure 14).

Analyses of domestic U.S. regulations by Apostolaki (2005) tended to support the above conclusions. She evaluated the comparative effects of two U.S. management measures: a minimum size regulation introduced in 1992 and creation of marine protected areas in 2000 to assist in reduction of swordfish discards by the U.S. fleet. She noted that adoption of a minimum size regulation could result in higher exploitation rates on older fish and concluded that the effectiveness of a minimum size regulation depends on post-release survival as well

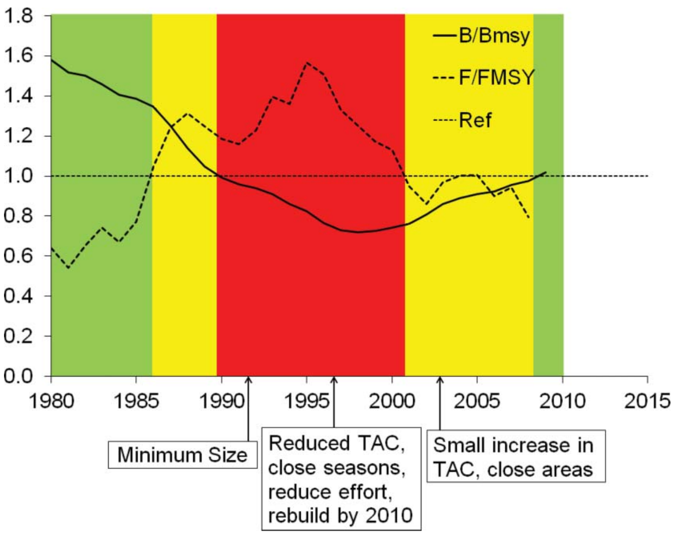

Figure 13 Timeline of relative biomass (B/B_{msy} and F/F_{msy}) for north Atlantic swordfish, based on production model analyses used to develop management advice. Colored zones: green, stock conditions considered consistent with the ICCAT Convention Objective; yellow, either $F > F_{msy}$ or $B < B_{msy}$; and red, $F > F_{msy}$ and $B < B_{msy}$. Vertical arrows indicate timing of significant management interventions.

as secondary effects that reduce the size of the fleet. By this, the removal of vessels from the fleet that were unable to travel to fishing grounds where larger members of the population occur was referred. A further secondary effect of minimum size limits is that such measures are often accompanied by import restrictions. Such restrictions impacted a fishery in the Caribbean Sea that was primarily based on smaller fish. This fishery was drastically reduced after the United States introduced size limits on swordfish imports in 1995–1996 (F. Arocha, Instituto Oceanográfico de Venezuela, personal communication, June 2012). However, the impact of such secondary changes on the trajectory of population recovery would likely occur several years after the implementation of the management measure, making it difficult to ascribe changes in exploitation rate and population biomass growth to its implementation.

Concerning the South Atlantic stock, the catch at size data available are not sufficient to assess whether the adoption of a minimum size regulation had some effect in reducing the rate of depletion of the stock. In this case, we believe that the establishment of TAC and catch limit measures has contributed significantly to the reduction of fishing mortality and the rebuilding of the South Atlantic stock. However, it is important to note that, as with the North Atlantic stock, even when the TAC has been set by ICCAT above the level recommended by SCRS, catches generally remained below the TAC established (Figure 14). This result suggests that other factors, such as market value and/or changes in fishing strategies, with changes in target species and fishing zones, have also contributed to the reduction in catches of the swordfish in the South Atlantic.

4 THE COMPARATIVE INVESTMENT IN RESEARCH

Over the period of rebuilding, scientists from ICCAT-member countries placed considerable emphasis on enhancing the understanding of the population dynamics of north Atlantic swordfish. A metric of this increased effort is presented in Figure 15, which illustrates the number of scientific papers pertaining to the North Atlantic stock produced by SCRS since 1990. Of interest is the comparative research effort applied to the two stocks. From 1990 to 2010, SCRS produced 62 scientific papers pertaining to the northern stock, while only 27 such contributions were made concerning the southern stock over the same period. The research effort peaked during the late

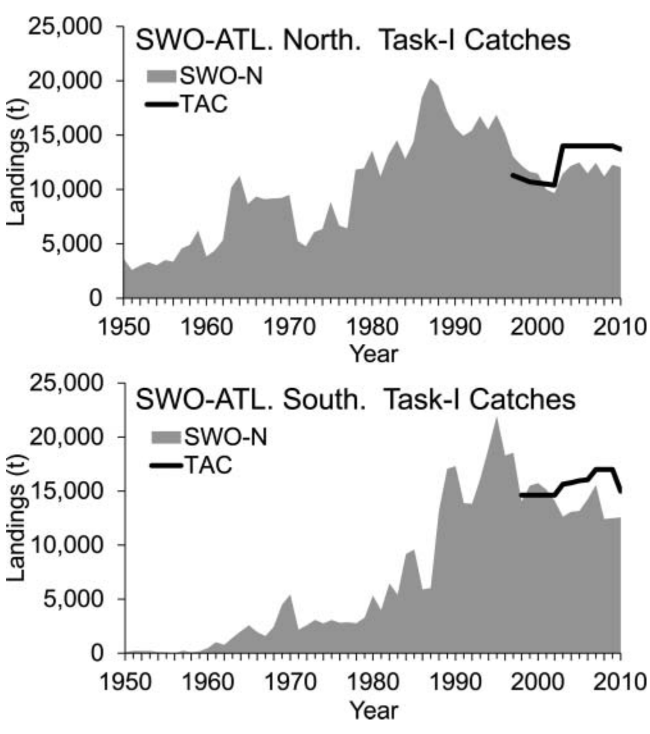

Figure 14 Swordfish landings in the North and South Atlantic, shown in relation to the total allowable catch (TAC).

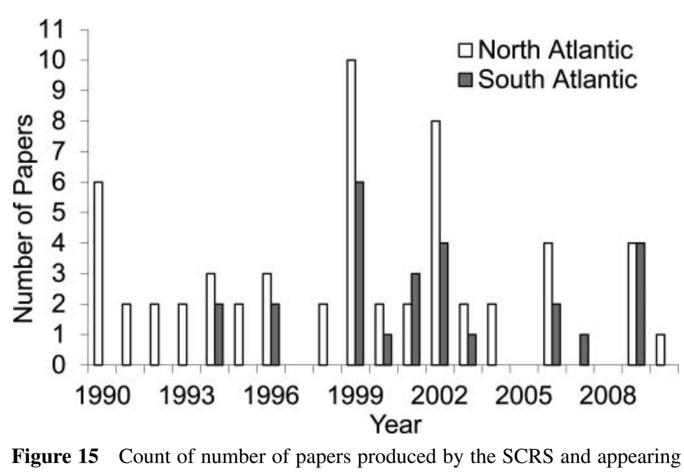

Figure 15 Count of number of papers produced by the SCRS and appearing in the Collective Volume of Scientific Papers (published annually) containing the key words "North Atlantic Swordfish" or "South Atlantic Swordfish" in the titles, 1990 to 2010.

1990s and early 2000s. During this period, key contributions for the northern stock included new or refined indices of stock abundance (e.g., Hoey et al., 1993), population models (e.g., Prager, 2002), improved understanding of stock structure (e.g., Alvarado Bremer et al., 1995, 1996, 1999, 2005, 2007), reproductive biology (e.g., Arocha and Lee, 1995; Arocha, 2002), growth (Arocha et al., 2003), tools for evaluation of the effectiveness of management measures such as time/area closures (Apostolaki, 2005), and evaluation of linkages between recruitment and the ocean environment (e.g., Mejuto, 2000). In contrast, for the southern stock, the contributions covered fewer topics and typically focused on development of catch rate series for swordfish in directed fisheries and as bycatch. While such research leading to more reliable indices of abundance for the southern stock was undoubtedly important and timely, there is no question that the comparative research investment in the northern stock was greater than in the south.

It could be argued that the greater investment in research has had tangible impact on the quality of the assessment advice. For example, the 2010 SCRS report (Anon., 2011) provides a precise estimate of MSY annual harvest levels for the North Atlantic stock (13,780 t) along with the 80% confidence interval, whereas only general guidance is given for the South Atlantic stock (≈15,000 t).

5 CHALLENGES TO MAINTAINING THE REBUILT CONDITION

5.1 Oversubscription of the Total Allowable Catch

ICCAT has established recent fishing plans (recommendations 06-02, 08-02, and 11-02) that include national quota shares that, when summed, exceed scientific recommendations for the annual TAC. However, the stock was still able to rebuild during this period as the catch still fell short of the total allowable catch (Figure 14). SCRS has noted that if the realized catches had been equal to the country-specific catches allowed by recommendation 06-02, the stock biomass would likely have declined, and the rebuilding plan would not have been fully successful. The most recent recommendation (recommendation 11-02) allows a potential catch of 15,195 mt, compared with a quota of 13,700 mt. ICCAT has, however, included a provision that if an individual contracting party to the ICCAT Convention exceeds its specified share in 2012 and 2013 (the period covered by recommendation 11-02), that party is obliged to reduce its share in the following year. Nonetheless, the current management arrangement could still result in total catches exceeding the scientific advice in a given year. Oversubscription of the TAC is not currently an issue for the south Atlantic stock, as the 15,000 mt TAC is not exceeded by the sum of the country-specific shares (recommendation 09-03).

5.2 Maintaining the Rebuilt Condition

Under the current ICCAT convention, fish stocks including swordfish are managed under the objective of "maintaining the populations of these fishes at levels which will permit the maximum sustainable catch (MSY) for food and other purposes" (Anon., 2007c, p. 5). This language is commonly interpreted as a definition of a "target" objective for each stock unit in ICCAT. Within the ICCAT convention, there are no provisions or guidelines for what constitutes an acceptable level of variability around this MSY target. Thus, currently for ICCAT, if a stock is found to be below the biomass level that allows the harvest of MSY (e.g., B_{MSY} reference point), then the stock is characterized as being in an overfished condition, and if the harvest rate is found to be above $F_{MSY,}$ it is categorized as being overfished (Anon., 2011).

However, excursions above and below the estimated B_{MSY} will normally occur in a fishery managed at MSY due to variations in recruitment and other biological and or environmental conditions (Kleiber, 2008). Thus, in the absence of an accepted variability or a limit reference point (LRP), the stock will fluctuate between an "overfished" and a healthy status if the biomass falls below B_{MSY} or above. It may be more practical to allow biomass to oscillate below B_{MSY} without triggering regulatory measures as long as it remains above an accepted biomass limit (B_{lim}) if B_{MSY} is going to be considered strictly as an objective target. Alternatively, target fishing mortality rates could be adopted such, that the expected probability of the stock excursion below B_{MSY} due to conditions of natural variability and or uncertainty in the estimation is negligibly low, therefore effectively establishing a target biomass (B_{targ}) that should be greater than B_{MSY}. Either way, it is then logical to define the "target" as a level that ought to accommodate natural variations of stock biomass without jeopardizing the health of the stock and comply with the Convention objectives of fishery resource management. For this reason, it is also useful to define an LRP less than the target benchmark, to be used as a trigger for management actions.

In a prior study, a simulation framework was presented using age structured models to explore the level of expected "natural" variability in fish stocks on total and spawning stock biomass (SSB) under different assumptions of stock-recruitment relationships and different levels of exploitation (Ortiz et al., 2010). We used this simulation framework model and applied it to the northern swordfish stock for evaluating biomass based limit reference points. Since the method requires an age-structured approach, we used the north Atlantic swordfish age-structured Virtual Population Analysis (VPA) model which was developed during the 2009 assessment[2] (Anon., 2010). The objective of this research was to examine the variability in biomass and SSB by projecting the age-structured fish population dynamics under

[2]It should be noted that the base model used to produce management advice for the 2009 north Atlantic swordfish assessment was a surplus production model (ASPIC).

diverse scenarios of exploitation and assumptions regarding the stock recruitment relationship. Under these scenarios, a potential LRP defined as $SSB_{lim} = SSB_{MSY}*(1\text{-}M)$ (where is M is the natural mortality parameter) was evaluated. This biomass limit reference point has been used in the past for other fish species (Restrepo et al., 1998; ICES, 2003). The objective was to evaluate if this biomass reference limit (BRP) is suitable for the case of northern swordfish for two specific measures:

1. An appropriate BRP should prevent triggering an overfished/overfishing status due to natural variability of the stock population (i.e., low probability of false positives) associated with recruitment variability.
2. It should also allow, within a reasonable margin of time, the detection of overexploitation of the stock that would require management actions (i.e., low probability of false negatives). Besides the rate of exploitation at MSY (F_{MSY}), we explored the dynamics of alternative proxies for MSY, commonly used in fisheries management (Restrepo et al., 1998; ICES, 2003), including the percent of spawners per recruit (% spawning potential ratio [SPR]) proxies ($F_{30\%SPR}$ and $F_{40\%SPR}$). These proxies have been suggested as more conservative and robust compared to the F_{MSY} reference level of exploitation, particularly if significant changes in fishing selectivity are observed or expected in the fishery (Goodyear, 1993; Restrepo et al., 1998).

The evaluations were performed by projecting the northern swordfish age-structured population during three consecutive time periods. During the first period, the population was projected at F_{ref} (F_{MSY} or a proxy) for 50 years to ensure that the population reached an equilibrium age structure. During the second stage, the population was then overfished (i.e., $F > F_{ref}$) at different levels and for different lengths of time. Then, during the final stage, the population was then allowed to rebuild by returning to the original target harvest rate of F_{ref}. During the rebuilding period, it was decided to use the fishing mortality $F_{ref,}$ because there are no current guidelines in the ICCAT convention on the time frame required to rebuild an overfished stock. Certainly faster recovery times can be achieved if more conservative measures ($F < F_{ref}$) are immediately implemented. Two alternative hypotheses of the stock recruitment relationship were considered for these evaluations:

1. A Beverton and Holt stock recruitment relationship estimated from the VPA stock biomass and recruits series (1978–2008, with no autocorrelation).
2. Constant recruitment (i.e., assuming recruitment as independent from the parent stock biomass). The latter was implemented using a random resample of the observed recruits from the same VPA time period (1978–2008). The conditions that varied during the simulations to generate multiple scenarios were:

- The fishing reference level F_{ref}[3] ($F_{MSY,}$ $F_{30\%SPR}$, and $F_{40\%SPR}$).
- The number of years of overfishing (2, 4, 6, 8, and 10).
- The level of overfishing (1.25, 1.5, 1.75, 2, 3, and 4 times the corresponding F_{ref}, e.g., $2 * F_{MSY}$).

The results indicate increased variability in stock biomass and stock spawning biomass when no relationship between biomass and recruitment was assumed (e.g., constant recruitment), in part due to the relatively poor correlation between stock biomass and recruits from the VPA model. Of course, an important difference is that under a constant recruitment assumption, even at a low stock biomass the population is able to produce recruits, in greater numbers than compared with other common stock-recruitment relationships. However, at the "optimal" level of exploitation (i.e., MSY), both the constant recruitment and Beverton and Holt stock recruitment relationships produced equivalent numbers of recruits. The distribution of SSB, stock numbers, and the yield (kg) were fished at levels of F_{MSY}, $F_{30\%SPR}$, and $F_{40\%SPR}$ assuming constant recruitment is summarized in Figure 16. In absolute values, the lowest levels of equilibrium spawning stock biomass and stock size were obtained when fishing at F_{MSY} (Figure 16). Equilibrium biomass at $F_{40\%SPR}$ was 51% lower than at F_{MSY}, while intermediate levels of biomass and stock numbers were obtained when fishing at $F_{30\%SPR}$. However, it should be noted that, on average, the yield expected under MSY was 20% higher compared to fishing at $F_{40\%SPR}$.

The next question we addressed was the "separation" between a target and limit biomass reference, taking into consideration the natural variability of the population, and the level of uncertainty about the estimation procedures. In the case of northern Atlantic swordfish, the variability associated with the stock-recruitment assumption was considered to be the sole source of "normal" variations in SSB. The average variability of the SRR relationship (σ) from the most recent age structured assessment (VPA) model was 0.16 in log-scale or approximately 16% coefficient of variation). Using this level of variation, 95% of the estimates of equilibrium SSB/SSB_{ref} for north Atlantic swordfish were between -0.10 and $+0.09$ fraction of SSB_{ref}, and 50% of the observations of SSB/SSB_{ref} (the 25th and 75th percentiles) were between -0.02 and $+0.02$ (Figure 17). In this case, with the LRP B_{lim} evaluated as $SSB_{lim} = SSB_{MSY} * (1-M)$, there was a very low probability that SSB was below SSB_{lim} [(P ($SSB < SSB_{lim} \leq 0.001\%$)] when the stock was fished at the F_{ref} harvest rate and the only source of biomass variability was the assumed stock-recruitment relationship (Figure 18). By most standards, a $<0.001\%$ chance would be considered a very low probability of an excursion below this limit due to natural variability.

In contrast, there is a considerable chance that decreases of SSB below the limit take place when the simulations include overfishing, as well as natural variation. This was evaluated by

[3]Fishing mortality to attain MSY or the equivalent F for different MSY proxies.

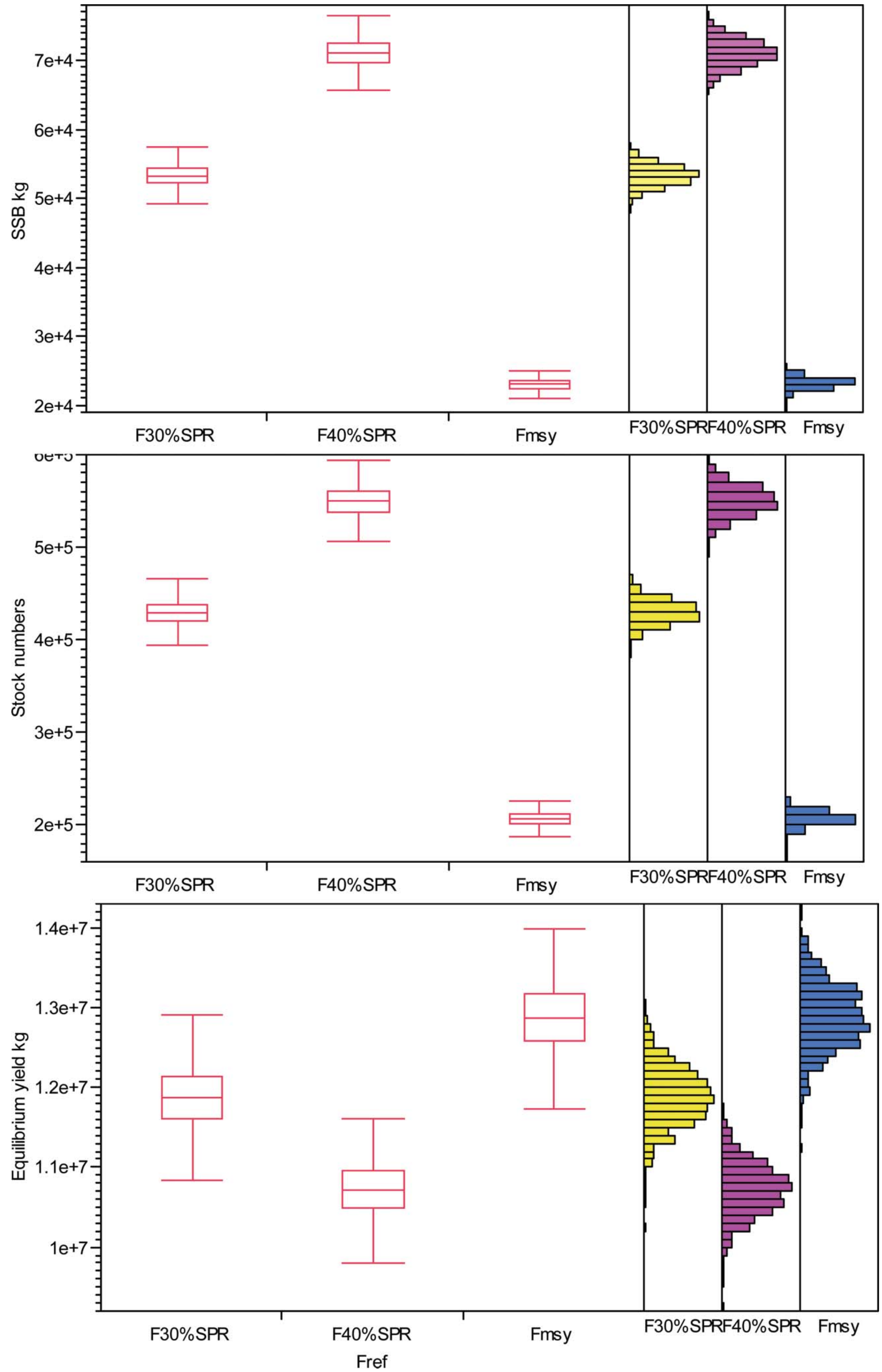

Figure 16 Distribution of equilibrium age structured spawning stock biomass (SSB kg; top), stock size (numbers of fish; middle) and yield (kg; bottom), for the north Atlantic swordfish stock under three fishing reference targets. F_{msy}, $F_{30\%SPR}$ and $F_{40\%SPR}$. The variance shown in the box plots and histograms corresponds to the natural variability due to the stock recruitment relationship, in this case constant recruitment is assumed.

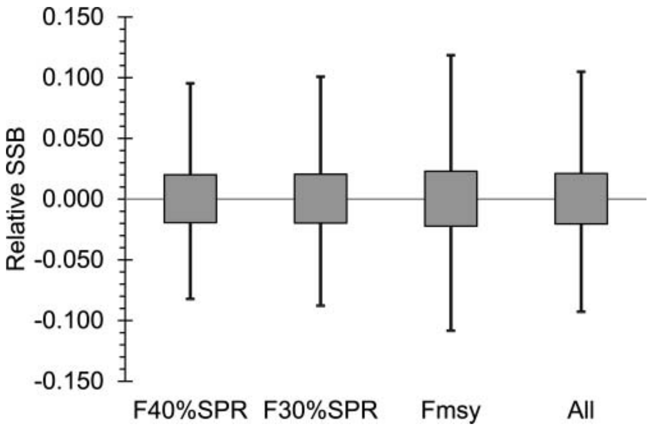

Figure 17 Relative distribution of SSB for individual and combined fishing reference targets evaluated for the North Atlantic swordfish stock. The box plot represents the 95th percentiles (whiskers) and the 50th percentile (box) over the F_{ref} (0 line).

determining the average proportion of cases where the SSB fell below the SSB_{lim}, once a period of overexploitation was initiated. The proportions of cases where SSB fell below SSB_{lim} varied as function of the exploitation rate (number of years * exploitation level) for the two fishing reference levels examined: F_{MSY} and $F_{40\%SPR}$ (Figure 19). In the cases simulated, when overexploitation occurred, the resulting overfished status was not generally detected, unless it took place for more than two years and at rates 25–50% higher than the F_{ref}, (i.e., before $P[SSB < SSB_{lim} \geq 50\%]$). Furthermore, the probability of detecting overexploitation was dependent on the chosen F_{ref}. For example, with the more conservative targets of $F_{40\%SPR}$, longer periods of overexploitation (four plus years) or much higher rates of overfishing (50% or greater) were required before detecting an overfished condition. In our simulations, overfishing at 25% higher than $F_{40\%SPR}$, even after ten years of overexploitation, resulted in only a 30% probability of SSB being below the proposed SSB_{lim}. These results indicated that under "natural" variability of recruitment, the northern swordfish stock is able to support excess fishing mortality rates (25% or less) for several years if fished at $F_{40\%SPR}$, without the SSB declining below the SSB_{lim}. However, that is not the case if the exploitation rate is at F_{MSY} (Figure 19).

The ability to determine that the stock is below a safe spawning biomass is important, because of the potential time for recovery if the SSB is allowed to decline too much. Biomass limits which are too low will likely result in longer rebuilding periods. Figure 20 summarizes the observed times of rebuilding (years to recover) in the simulations as a function of the overexploitation level in SSB. Depending upon the F_{ref} and the level of overexploitation, even a few years of overexploitation (i.e., two years) can cause the stock to become rapidly depleted to levels as low as 70% of the SSB_{ref}. In these cases, the rebuilding phase, following a F_{ref} management strategy, can last 5 to 20 years. Of course, these recovery times are also dependent on the selectivity pattern (Ortiz et al., 2010).

In response to this, and related scientific advice regarding incorporation of precautionary fishery management, ICCAT has recently adopted a decision framework (recommendation 11–13) which identifies the general goals and timeframes for rebuilding to and/or maintaining stocks at levels that can support MSY, while accounting for scientific uncertainties and risk of failure tolerance. This framework represents a form of harvest control rule that, when followed, should result in achieving, on average, a biomass buffer sufficiently large to accommodate natural variations in stock biomass without jeopardizing stock health.

5.3 Complex Stock Structure, Metapopulations, and Protection of Stock Components

> We were drinking beer in the Legion in Ingonish (Cape Breton Island) and the bartender said "You guys aren't very good swordfishermen"—that was a real insult, then—and we said, "Why not?" and he said "Well, there goes one." He could see a swordfish from the window of the Legion (Respondent #29, cited in Fitzgerald, 2000, p. 14).

As noted earlier, there is general consensus that the three management units currently used by ICCAT for stock assessment purposes (North Atlantic, South Atlantic, and Mediterranean Sea [Figure 8]) are adequate. A recent workshop dealing with stock structure of swordfish in the Atlantic and Mediterranean reviewed results of biological and genetic studies and tagging programs and concluded that the available data generally support these hypotheses (Anon., 2007a). However, within each of the management units there may be finer-scale structuring of the populations that warrant consideration.

For example, within the range of Atlantic swordfish, there are examples of local depletion events for both the North and South stocks. From the North Atlantic stock, Fitzgerald (2000) describes a harpoon-based swordfish fishery off coastal Cape Breton Island, Canada, that had peak landings of more than 2000 metric tons (dressed weight; Figure 21). It is noteworthy that those landings from a comparatively restricted geographic area exceed current Canadian landings from a much broader area stretching from Georges Bank to the southern Grand Banks of Newfoundland (Figure 22). Current landings from Cape Breton are <1 mt, while swordfish fisheries further offshore have comparatively high catch rates, indicating that this stock component has not yet recovered in spite of the relatively healthy state of the overall management unit.

From the South Atlantic, another coastal swordfish fishery appears to have shown localized depletion. The Agulhas Bank region off South Africa (Figure 23) is almost at the southern extreme of the swordfish geographic distribution, with large females contributing to the bulk of the catch in this area. The stock origin of these fish is assumed to be South Atlantic, but it is also possible they are associated with the Indian Ocean.

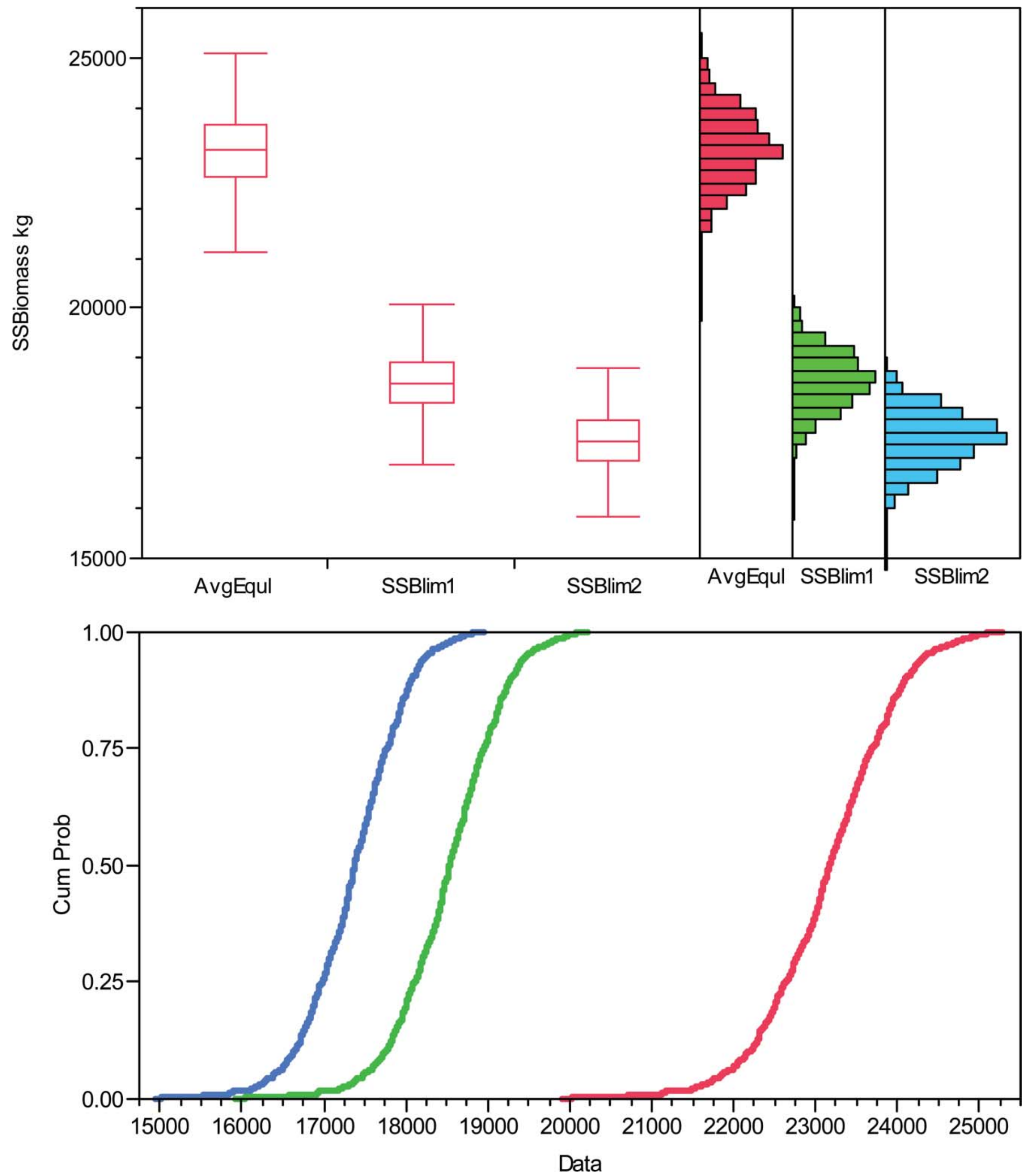

Figure 18 Distribution (top) and cumulative density (bottom) plots for North Atlantic swordfish for the equilibrium SSB (kg) at F_{msy} and the corresponding SSB_{lim} reference points evaluated: $SSB_{lim1} = SSB^*(1\text{-}M)$ (where M equal natural mortality 0.2), and $SSB_{lim2} = 75\%^*SSB_{msy}$.

Generally, no fish in spawning condition are found in this region. Hence, this area appears to be a rich feeding ground for large female swordfish that are able to make the migrations so far south. Until late 1997 (east) and early 1998 (west), no longline fishery operated there, but international fleets operated further east and west outside of the South African Bank area in 1997/1998, catch rates in a recreational tournament fishery for swordfish declined markedly (Figure 24) and have not recovered since. In both examples of local depletion described here, it is noteworthy that the coastal populations have not recovered, even when the ICCAT assessments of the larger management units indicate that the stocks have rebuilt to the MSY target.

6 DISCUSSION

From our review, it is clear that swordfish possess unique attributes and adaptations that contribute to resiliency. However, it is possible to argue that such adaptations are often shared by other commercially-exploited large pelagic species, and by extension, cannot fully account for the resilience of Atlantic swordfish stocks. For example, swordfish and other billfish have adaptations that facilitate foraging in colder water conditions. Brain and eyes are kept up to 13°C above ambient by a novel heater organ derived from the skeletal muscle around the eyes (Block, 1991). While swordfish have such cranial adaptations, 13 species of Scombrid tunas and 5 species of lamnid sharks

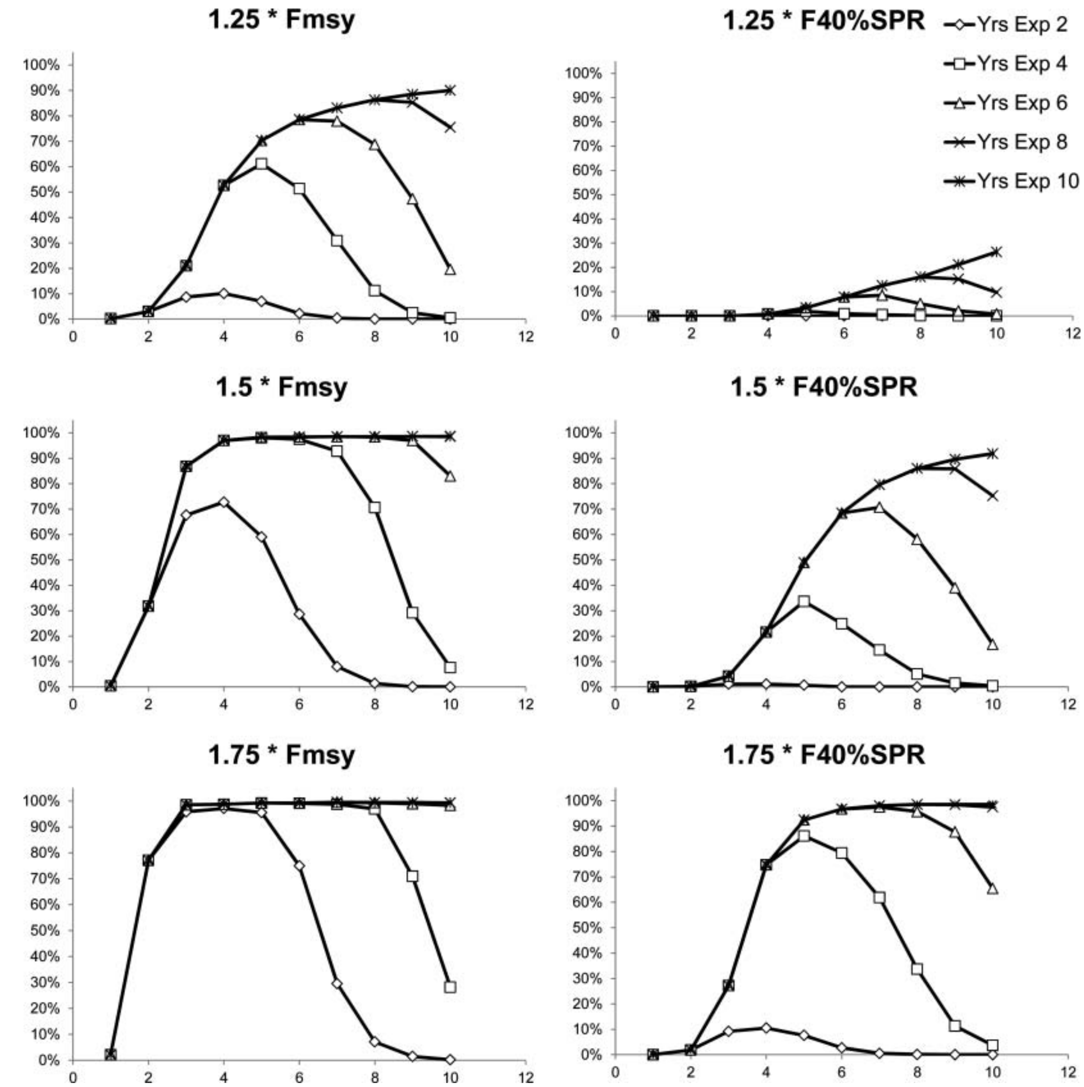

Figure 19 Proportion of cases where the SSB for the North Atlantic swordfish was below the SSB_{lim} (SSB_{MSY}*(1-M)) after a number of years of exploitation (x-axis), times the level of overexploitation (rows) for the F_{ref} of F_{MSY} and $F_{40\%SPR}$. The legend gives the results of the simulations for different durations of the period of exploitation, ranging from 2 to 10 years.

use other adaptations to achieve endothermy, in some cases maintaining internal temperatures 21°C above ambient (Costa and Sinervo, 2004).

Atlantic swordfish also do not exhibit schooling behavior, in contrast to many other members of the Scombridae. In consequence, sources of fishing mortality are typically hook-and-line and to a lesser extent harpoon fisheries and driftnets, and do not include purse seine fisheries or other gear designed to take advantage of schooling behavior, which are more efficient modes of capture. However, as long as all sources of mortality are accounted for, it seems axiomatic that the modalities of fishing should not influence stock robustness.

However, some attributes such as reproductive biology, may have positively affected the rebuilding potential of Atlantic swordfish stocks. Swordfish, along with blue marlin and northern bluefin tuna, are among the largest scombrids with the largest and heaviest (>10,000 g) mature gonads when they are ready to spawn (Baglin, 1982; Arocha, 2002; Luckhurst et al., 2006). It is a unique attribute shared only by these large pelagic and highly migratory species, but how these species spawn can make the difference in how resilient they are to fishing pressure. The advantage swordfish is likely to have over its counterparts is that its broadcast spawning of a large number of eggs in response to large-scale spatial and temporal patchiness in food supply or suitable habitats, spans over a broader spatial range and over a prolonged time in different habitats than its counterparts. Swordfish are highly fecund, like blue marlin and bluefin tuna. Although it appears that swordfish has an order of magnitude higher fecundity than western bluefin tuna (setting potential biases in bluefin tuna fecundity estimates aside), not all spawned eggs are equal. Therefore, fecundity by itself is not a clear indicator of resilience to fishing pressure; it is likely a

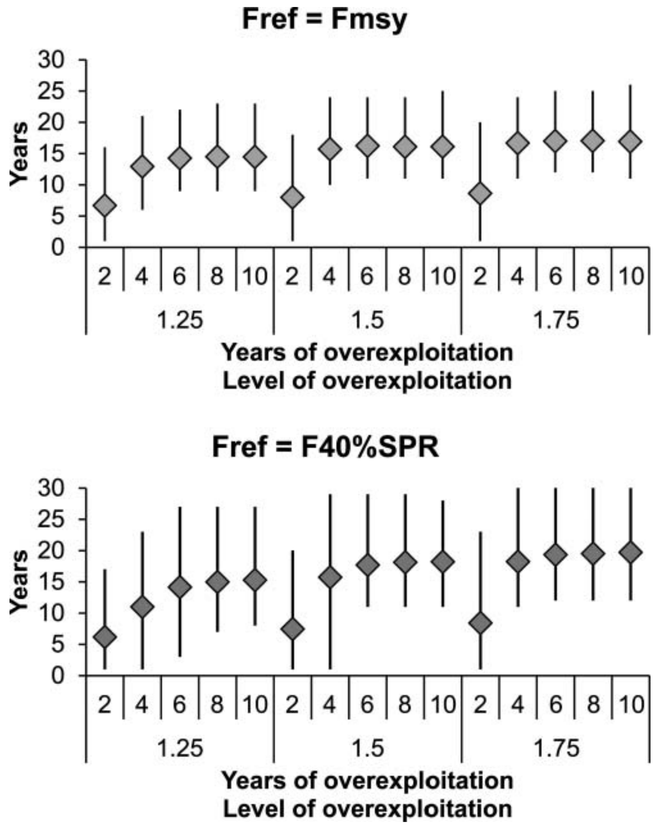

Figure 20 Years to recover the SSB for the North Atlantic swordfish to the reference level (SSB_{MSY} or $SSB_{40\%SPR}$) following overexploitation by 2 to 10 years, and level of overexploitation (1.25, 1.5, and 1.75 times F_{ref}). The diamond represents the average years, and the bar the low and high percentiles (0.10, 0.90).

combination of other life history traits like spawning time and spawning grounds (Sadovy, 2001).

Swordfish has a protracted spawning season (December–August) over a broad range of habitats in the North Atlantic. Larger, older, mature swordfish spawn in the main spawning grounds southwest of the Sargasso Sea, then move north (after May) to feed in more productive waters; while younger mature swordfish, likely more resident in the subtropics, spawn in areas of strong current systems (i.e., Windward Passage, Yucatan Channel, Gulf of Mexico Loop Current, southeastern U.S.–Gulfstream) with ample prey species, and warm waters. In the South Atlantic, spawning takes place all year in the equatorial Atlantic, and seasonally in adjacent subtropical waters. In contrast, bluefin tuna has a short spawning season (May–July) and is restricted to comparatively localized spawning locations in the Mediterranean Sea and Gulf of Mexico (Mather et al., 1995; Medina et al., 2002). Such behavior and concentrations facilitate the vulnerability of bluefin tuna to some fishing gears. Similarly, blue marlin in the northern Atlantic appears to have a protracted spawning season, but shorter than swordfish (May–October) and spawning is likely restricted to the open waters around the Greater Antilles and off Bermuda (Erdman, 1968; Luckhurst et al., 2006). The broadcast spawning displayed by swordfish over different areas of the Atlantic along with the reduction in fishing effort in important spawning grounds may have contributed to the recovery of the stocks.

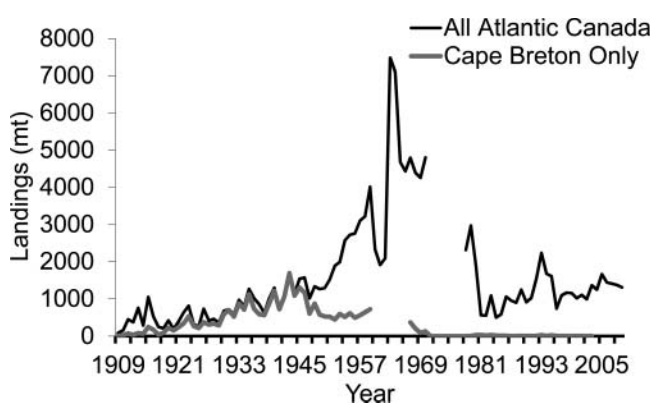

Figure 21 Landings (round) of Atlantic swordfish off Cape Breton Island (Nova Scotia, Canada) compared with all Atlantic swordfish landings by Canada, 1909 to 2009. Data sources: Canadian series: Tibbo et al., 1961 (1909–1949) and ICCAT Task 1 (1950–2009); Cape Breton series: Tibbo et al., 1961 (1909–1959) and Department of Fisheries and Oceans Canada data (1967–2003).

In addition to reproductive characteristics, growth rate could be considered an important contributor to stock robustness. We have shown that swordfish exhibit comparatively fast growth, particularly at younger ages (Figure 6). Sogard (1997) noted the logically intuitive hypothesis that larger or faster growing members of a cohort gain a survival advantage over smaller conspecifics via enhanced resistance to starvation, decreased vulnerability to predators, and better tolerance of environmental extremes (see Biro et al. [2006] for a contrasting perspective). If the postulated advantage of rapid growth among conspecifics could be extended to interspecific comparisons among large pelagic fish species, rapid growth may mean that the contribution of elements of natural mortality such as predation to the total mortality experienced by swordfish is less than that experienced by slower-growing species.

Some records from high-latitude fisheries, suggest that some of the largest females can occur in areas where fisheries are now almost non-existent or very rare events. Such swordfish were found off Sweden and Norway, where Linnaeus observed them. Goode (1883) described the occurrence of large female swordfish off Denmark and into the Baltic Sea. Most of the current fishing effort is now targeting the medium size-weight individuals which are the most abundant part of the population available in the oceanic regions between the temperate limits of both hemispheres. Assuming that the occurrences of large females at high latitudes still persist, they may act as a reservoir of spawners, but that possibility is yet to be demonstrated.

It is possible that the aforementioned life history characteristics make swordfish stocks more resilient to fishing pressure than the stocks of other large pelagic species, but it is doubtful that stock recovery of the Atlantic stocks would have been achieved without appropriate management actions. The neighboring Mediterranean swordfish stock for which harmonized

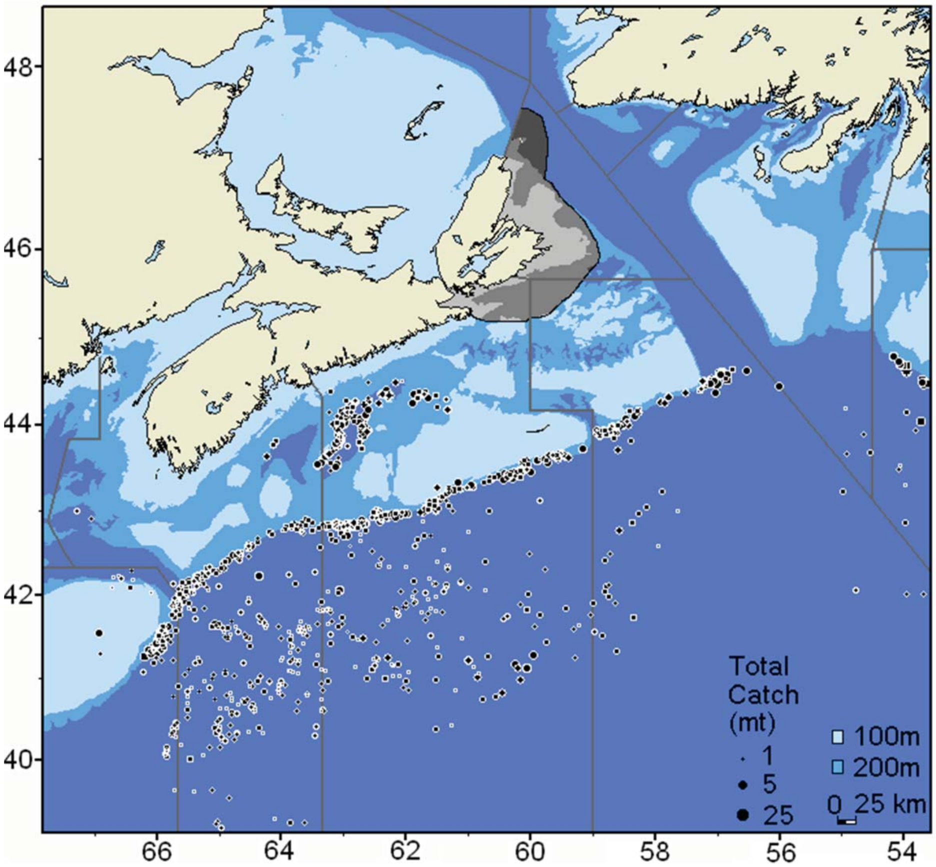

Figure 22 Spatial distribution of observed swordfish catches in the Canadian fishery (Maritime region). Points indicate aggregated weight (kg) of swordfish caught on observed vessels from 2001 to 2011. Grey area indicates the estimated range of the swordfish fishery prior to 1950.

management actions have been only recently implemented is considered to be heavily overfished (Anon., 2011). Although comparisons among areas are difficult due to differences in the oceanographic conditions and the fisheries exploitation pattern, it can be argued that the Mediterranean swordfish stock has some further biological advantages over its Atlantic counterpart, such as earlier age at maturity and fewer predation risks given that shark populations are depleted in the epipelagic system in the Mediterranean (Tudela, 2004), and the comparatively higher recruitment levels in the Mediterranean compared with the North Atlantic stock, considering their respective sizes-areas of distribution. The very high abundance of young swordfish in the Mediterranean seems to be a particular feature of the stock.

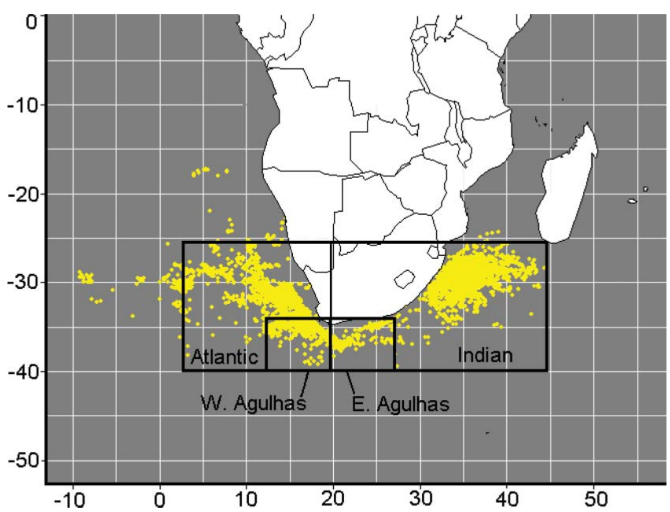

Figure 23 Agulhas bank region off South Africa, showing the distribution of South Atlantic swordfish catches during the period 2001 to 2004.

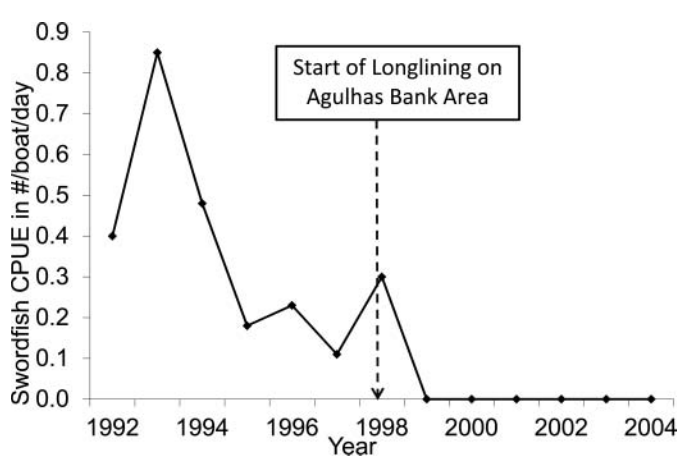

Figure 24 Catch rates of South Atlantic swordfish observed in the recreational fishing tournament known as the "Broadbill Classic." The timing of the introduction of longlining fishing effort on the Agulas Bank is shown by the blue line.

Descriptions of the effects of overfishing in the Mediterranean and the large amount of young fish caught and discarded have been reported since the middle of the 18th century by Spallanzany's testimony (Goode, 1883). It seems, however, that favorable life history traits are not sufficient to ensure stock sustainability and complementary management actions are probably needed.

Among the management actions undertaken by the RFMO, it appears as though introduction of a minimum size regulation was largely ineffective in terms of directly reducing overfishing and stock depletion (Figure 13). However, some positive effects were observed in some countries, as there were economic disincentives to landing fish smaller than the minimum size. However, limiting the total exploitation of the stock through introduction of TACs appeared to be most beneficial in the case of the Atlantic, as were the establishment of closures of various types intended to reduce mortality on juvenile swordfish. Additionally, some countries adopted domestic measures (starting in the mid-1990s) that controlled or reduced fishing capacity, fishing operations, licensing, and further restricted fishing from critical areas for small swordfish, all designed to reduce overall fishing mortality.

The Organization for Economic Co-Operation and Development (OECD) convened a recent workshop to examine the economics of rebuilding fisheries, and concluded that the rebuilding of Atlantic swordfish represents a notable success for ICCAT (OECD, 2010). They noted that ICCAT has instituted a transparent process with respect to scientific data, and all member countries are able to contribute to the process of assessment and the generation of scientific advice. The rebuilding of the stock, they conclude, resulted from increasingly stringent management measures, and annual catches that were less than the TAC in recent years, as well as species-specific biological attributes such as rapid growth. The conclusions of the OECD support our own view: the resurgence of the Atlantic swordfish stocks was due to appropriate and timely management interventions as well as biological robustness. Further, we would add that the considerable investment in science described in section 4 provided the foundation for the effective conservation measures adopted by ICCAT.

However, these conclusions must be tempered somewhat, given the conclusion of SCRS in 2007 that had countries participating in the fishery taken their full allocations as laid out in recommendation 06-02, the rebuilding of the stock may not have been fully achieved, at least within the intended time-frame. The rebuilding of the stock also benefitted from a period of relatively good recruitment (from 1997 to 2001, Figure 7), that coincided with decreasing fishing mortality (Figure 13), as measures contained within the recovery plan started to take effect.

Our review provides several suggestions to help ensure that Atlantic swordfish stocks retain their relatively healthy status. Firstly, as suggested by the 2009 *Report of the Independent Performance Review of ICCAT* (Hurry et al. 2009), ICCAT could adopt a more precautionary approach to management of stocks within its mandate. In fact, ICCAT has already indicated its interest in relation to North Atlantic swordfish. Recommendation 10-02 (p. 2) states that:

> In advance of the next assessment of North Atlantic swordfish, the SCRS shall develop a Limit Reference Point (LRP) for this stock. Future decisions on the management of this stock shall include a measure that would trigger a rebuilding plan, should the biomass decrease to a level approaching the defined LRP as established by the SCRS.

Based on the age-structured model used in the last assessment for northern Atlantic swordfish, a proposed biomass limit of $SSB_{lim} = SSB_{MSY}$*(1-M) (80% below SSB_{MSY}) could be used as a limit reference point that will have very low probabilities of indicating depletion of spawning stock biomass in the absence of overexploitation (i.e., only normal variation due to stock recruitment variability). However, caution should be noted as the simulation results suggest that such a level of depletion could occur, on average, from harvest rates about 25% above the reference level ongoing for 2–4 years (a typical inter-assessment time frame) regardless if F_{MSY} or the evaluated proxies for MSY are used. Another important conclusion of the simulation studies was the long time required to rebuild the spawning stock biomass to a given reference level when following a F_{ref} management strategy during the recovery period. Thus, setting a limit well below SSB_{MSY}, while having the desirable quality of statistical power for detecting a stock has been overexploited, could well result in extended periods of overexploitation, with possibly extended time periods for management actions required for rebuilding. More rapid recovery can be accomplished with more restrictive measures. But this, of course will likely translate in larger quota reductions at the beginning of the recovery periods. If the objective is to maintain stocks at or above the expected B_{MSY} level (*i.e.,* treat F_{MSY} or its proxy as a limit reference), then a lower reference F (and higher SSB) with suitably low risks of biomass excursion below SSB_{MSY} in the absence of overfishing, should be chosen as targets such as the percent spawner per recruit (% SPR) based reference points.

Adoption of such reference points and following the decision framework adopted by ICCAT in recommendation 11-13, should result in sustainable fishery management for swordfish (and other) ICCAT stocks.

A second action that ICCAT should pursue is avoiding the oversubscription of the TAC established by SCRS (see section 5.1). As noted earlier, catches of the magnitude permitted under the recent fishing plans could have compromised the successful rebuilding of the North Atlantic stock. While the practice of using so-called "ICCAT math," where the allocations agreed in a management measure exceed (sometimes by a large amount) the stated scientific advice, the approach has been successfully used for swordfish and a range of other species to achieve consensus. However, it is also clear that the policies established through these agreements imply tolerance for continued overfishing and would not be considered precautionary nor in compliance with the ICCAT Convention conservation objectives.

Finally, the evidence starting to accumulate from the relatively new technique of satellite archival tags (see section 2.5) points to the possibility of finer-scale spatial structuring of the stocks than is currently understood. If these hypotheses are borne out with further study, then a more spatially-explicit management scheme may have benefits for stock conservation. Such an approach could offer greater protection for sub-components of the management units, and potentially avoid localized depletions as described earlier.

ICCAT should also be mindful of the benefits of comprehensive research efforts, as illustrated for the north Atlantic stock. Such an investment in research needs to be, at the least, maintained for the North Atlantic, and possibly expanded for the south Atlantic stock, where the research effort is shown to be less comprehensive compared with the North (see section 4). Some examples of areas requiring research effort are listed in the report of the 2006 ICCAT Workshop on Swordfish Stock Structure (Anon., 2007) which highlighted the need for more detailed genetic investigations in the South Atlantic, as well as continued conventional and electronic tagging.

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