SCRS/2015/111 Collect. Vol. Sci. Pap. ICCAT, 72(8): 1949-1969 (2016)

EVIDENCE OF SPAWNING IN THE SOUTHERN SARGASSO SEA OF FISH SPECIES MANAGED BY ICCAT - ALBACORE TUNA, SWORDFISH AND WHITE MARLIN

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SUMMARY

The spawning area of three species managed by ICCAT – albacore tuna, swordfish, white marlin – in the southern Sargasso Sea is described. The significance of the Subtropical Convergence Zone (STCZ), an important oceanographic feature is highlighted. Albacore tuna are shown to spawn in March and April between 20°- 23º N. and 60°-70º W., in proximity to the STCZ. Female swordfish in spawning condition were sampled from a larger latitudinal range (18°- 25º N.) and further east (55°- 65º W.). Swordfish spawning occurs from December to June within the subtropical area (13°–35° N.), but appears to be more intense in the southern Sargasso Sea. White marlin spawn in essentially the same area as albacore from April to June. The overlap of the spawning areas between the three species during similar time periods and in proximity to the STCZ suggests that some management/conservation measures should be considered. An analysis of the ICCAT catches for these three species for the southern Sargasso Sea (20°-30º N.) indicates that these catches are not generally a significant contributor to the Sargasso Sea as a whole.

RÉSUMÉ

Le présent document décrit la zone de frai des trois espèces gérées par l'ICCAT, le germon, l'espadon, le makaire blanc, dans le sud de la mer des Sargasses. L'importance de la zone de convergence subtropicale (STCZ), une caractéristique océanographique notable, a été mise en exergue. Il s'avère que le germon fraie en mars et avril entre 20 et 23ºN et 60-70ºW à la proximité de la STCZ. Les femelles d'espadon en état de se reproduire ont été échantillonnées dans une frange de latitude plus large (18°- 25° N) et plus à l'Est (55°-65º W). Les espadons fraient de décembre à juin dans la zone subtropicale (13°-35° N), mais il s'avère que le sud de la mer des Sargasses est l'une des zones de concentration de reproduction les plus intenses. Le makaire blanc fraie fondamentalement dans la même région que le germon, d'avril à juin. Le chevauchement des zones de frai des trois espèces pendant des périodes similaires et à proximité de la STCZ donne à penser qu'il conviendrait d'envisager certaines mesures de gestion/conservation. Une analyse des captures de l'ICCAT de ces trois espèces dans le sud de la mer des Sargasses (20°-30º N) indique que ces prises ne représentent pas de grande contribution aux prises de la mer des Sargasses dans son ensemble.

RESUMEN

Se describe la zona de reproducción de tres especies gestionadas por ICCAT -atún blanco, pez espada y aguja blanca - en la parte meridional del mar de los Sargazos. Se resalta la importancia de la zona de convergencia subtropical (STCZ) como rasgo oceanográfico. Se sabe que el atún blanco desova en marzo y abril entre 20°- 23º N y 60°-70º W, en las proximidades de la STCZ. Se muestrearon hembras de pez espada en condiciones de procrear desde un rango de latitud más amplio (18°- 25º N) y más al Este (55°- 65º W). El desove del pez espada se produce desde diciembre hasta junio dentro de la zona subtropical (13°–35° N), pero parece más intenso en la zona meridional del mar de los Sargazos. La aguja blanca desova en prácticamente la misma zona que el atún blanco de abril a junio. El solapamiento de las zonas de desove de las tres especies durante períodos de tiempo similares y en las inmediaciones de la STCZ sugiere que deberían considerarse algunas medidas de ordenación/conservación. Un análisis de las de capturas de ICCAT para estas tres especies en el mar de los Sargazos meridional (20°-30º N) indica que las capturas de esta zona no representan, por lo general, una contribución significativa a las capturas del mar de los Sargazos en su conjunto.

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KEYWORDS

Sargasso Sea, Spawning, Albacore tuna, Swordfish, White marlin, Blue marlin, Porbeagle shark, Oceanography

Introduction

The Sargasso Sea, situated within the North Atlantic Subtropical Gyre, has a unique pelagic ecosystem based upon two species of floating golden-brown algae of the genus *Sargassum.* It is bounded by the clockwise flow of major ocean currents on all sides with the Gulf Stream, forming its western boundary (**Figure 1**), being the most influential current as it transports quantities of *Sargassum* northward from areas such as the Gulf of Mexico (Laffoley *et al*. 2011). This ecosystem provides essential habitat for key life history stages of a wide variety of species and hosts a highly diverse community of associated organisms. The formation of rings and eddies along the eastern margin of the Gulf Stream helps to concentrate *Sargassum* and carry it into the Sargasso Sea. The Subtropical Convergence Zone (STCZ), where warm and cold water masses meet, occurs between 22° and 30°N in the southern sector of the Sargasso Sea, and it is here that distinct thermal fronts occur in the upper 150 m of the ocean from fall through spring (Halliwell and Cornillon 1990). *Sargassum* with its associated community accumulates in this area so the fronts are an important feeding area for pelagic fishes in the Sargasso Sea (Laffoley *et al*. 2011). As we show in this paper, the STCZ is also an important spawning area for several different ICCAT- managed species. Within the Sargasso Sea the SSC has focussed previously upon an area extending from 22°– 38ºN and from 76º– 43ºW; this paper focuses largely on the southern latitude band from 20°– 30° N (**Figure 1**).

The Sargasso Sea plays an important role in the ecology and life history of a number of large pelagic fish species many of which are apex predators. In seeking to demonstrate the importance of the Sargasso Sea and its associated pelagic ecosystem, the SSC has analysed the biology and ecology of highly migratory fish species found in the Sargasso Sea (Luckhurst 2014a; Luckhurst 2014b). Most of these species are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). A number of these species are believed to spawn in the Sargasso Sea on a seasonal basis but there is a scarcity of geo-referenced information with respect to the spawning location of the various species. In this paper, we present data on the spawning of three of the principal species managed by ICCAT - albacore tuna (*Thunnus alalunga)*, swordfish (*Xiphius gladius*) and white marlin (*Tetrapturus albidus*) from the southern Sargasso Sea in the latitude band 20°– 25º N. We also provide evidence of spawning of blue marlin (*Makaira nigricans*) and wahoo (*Acanthocybium solandri*) around Bermuda (32º N.), north of the STCZ, from previously published information (Luckhurst *et al.* 2006; Oxenford *et al.* 2003). The habitat, migration and movement patterns of all of the species noted above, in relation to the Sargasso Sea, are discussed in Luckhurst (2014a). The importance in the reproductive cycle of porbeagle sharks (*Lamna nasus*), another species managed by ICCAT, is highlighted by the discovery of a pupping ground for this species in the southern Sargasso Sea (Campana *et al*. 2010).

Subtropical Convergence Zone (STCZ)

The oceanic STCZ in the North Atlantic is the latitude band typically centered between approximately 22º and 30º N where one or more surface oceanic fronts are usually observed within this band and where sea surface temperature (SST) changes of 1º-3º C can occur within distances of only a few kilometers (Halliwell and Cornillon 1990). A single frontal zone up to 3 degrees of latitude wide was the principal large-scale frontal feature in the SST analysis conducted in the STCZ (Halliwell and Cornillon 1990). In terms of longitude, the STCZ is generally found between 45º and 70º W (Bischof *et al.* 2004).

The dominant signal in the annual cycle of SST is a zonally symmetric N- S movement of isotherms. The amplitude of the annual cycle is higher in the northern part of the domain than in the south such that large-scale, latitudinal SST gradients decrease during the summer and increase during the winter (Hanson *et al.* 1991). The relatively strong large-scale frontal band between about 25º and 30º N virtually disappears in summer. During this season the strongest SST gradients in the Sargasso Sea are found north of 30º N. Maximum gradients occur in late February/early March and minimum gradients occur in early August at the time of the highest SSTs. The zone near 28º N in February is shown to be a favorable time and place to observe large mean temperature gradients and some significant downwelling has been observed (Hanson *et al.* 1991). The average SST ranges from 26º C in the southern part of the STCZ to 23º C in the northernmost section (Bischof *et al.* 2004).

The long-term (20-year) mean mixed layer depth shows that the mixed layer is shallower in the region where the fronts are usually found and that the mixed layer is deeper both to the north and south of this latitude band. The pattern is distinctly zonal with the shallowest mixed layer typically occurring at about 28º N (Hanson *et al.* 1991). The seasonally averaged mixed layer depth is deepest in winter, when it is deeper than 80 m everywhere and is deeper than 150 m in the extreme northern part of the STCZ. In both spring and fall, there are strong horizontal gradients in mixed layer depth, whereas in summer the mixed layer is at its shallowest and is more uniform (Hanson *et al.* 1991).

Many large pelagic fishes seek out fronts for both forage and migration but in a preferential way, i.e., they seek out definite subdomains of the frontal zone environment (Olson *et al.* 1994). Some longline fisheries target frontal zones with an expectation of higher catch rates, e.g. the Hawaiian swordfish fishery (Seki *et al.* 2002). However, there are generally inadequate data to demonstrate causal relationships and, as a consequence, direct responses of organisms to the conditions found along frontal zones have not often been demonstrated (Owen 1981). Frontal zones are areas where mixing processes near the interface of two different water masses can create a zone of concentrated food particles that can ultimately attract larger nektonic predators to the locally enriched trophic web (Arocha and Bárrios 2009). *Sargassum* can often collect at surface-convergent fronts like the STCZ and these mats can subsequently attract other organisms leading to aggregations of meso- and apex predators which are most commonly there to feed (Owen 1981). Dolphinfish are known to be closely associated with *Sargassum* mats where they feed on associated organisms and flyingfish lay their eggs on *Sargassum* mats (Luckhurst 2014a). In turn, dolphinfish are a primary prey group for both tunas and billfish (Luckhurst 2014b) so that frontal zones with associated *Sargassum* may have higher densities of prey species such as dolphinfish.

There appears to be a lack of evidence of nutrient enhancement boosting primary production levels in the STCZ but the temporal patterning of spawning by pelagic fishes described here suggests a strong association with a set of oceanographic conditions which are most pronounced in the spring months.

Spawning Area and Seasonality

Albacore tuna

Albacore are multiple or batch spawners, shedding batches of hydrated oocytes, in separate spawning events, directly into the sea where fertilization occurs. There is a close relationship between spawning and sea surface temperature: temperatures above 24ºC seem to stimulate maturation and reproductive activity (ICCAT 2010a). It has been suggested that spawning might be synchronized with high temperatures in order to enhance growth of eggs and larvae (ICCAT 2010a). Spawning areas of the North Atlantic albacore stock include the subtropical waters of the southern Sargasso Sea, waters offshore from Venezuela and the Gulf of Mexico (ICCAT 2010a). In the north Atlantic as a whole, reproduction is known to occur from April till September but the peak of spawning occurs around July (ICCAT 2010a). Here we present data which suggests a more abbreviated spawning period (March, April) in the southern Sargasso Sea (**Table 1**) in the region of the STCZ. These data were collected opportunistically by observers on Venezuelan longline vessels over a period of nine years (1995 – 2003). There are no data available from September to December as there was apparently little fishing effort in this area during this period. A plot of the locations where spawning albacore were sampled (Fig. 2) indicates a relatively circumscribed area between 20º - 23º N and 62º - 70º W. This appears to be in the STCZ or just south of it. The average annual temperature in this southern latitude zone is 26º C. (Bischof *et al.* 2004) which is in the preferred temperature range for albacore spawning (ICCAT 2010a). In the eastern Pacific off California, albacore fitted with ultrasonic tags were tracked in the vicinity of a frontal zone and were shown to concentrate near this zone. This concentration was attributed to the presence of an upwelling zone which offered enhanced feeding opportunities (Owen 1981). The concentration of albacore moved away as the frontal zone degraded. Albacore were also seen to move more slowly when crossing fronts and to spend little time on the colder side of the front indicating a thermal barrier effect (Owen 1981). This behavior could result in higher concentrations of albacore on the warm side of thermal fronts possibly inducing spawning in this area when favorable conditions exist.

Swordfish

As for many tuna species, swordfish spawning is strongly influenced by environmental factors, especially temperatures in the epipelagic zone. Based on various indicators, it was concluded that the reproductive activity of females appears to be largely restricted to the warm tropical regions of the western Atlantic (ICCAT 2010b). In the north Atlantic, swordfish generally spawn ideally at temperatures from 23º to 26°C (Beardsley 1978). Swordfish spawn all year round in the northwest Atlantic, with a peak in reproductive activity between December and June (Beardsley 1978; Arocha 2007). The traditional spawning areas of this species are in the Gulf of Mexico, south of the Sargasso Sea, east of the Antilles, in the Strait of Florida and along the southeast coast of the United States (Arocha 2007). There is a segregation of the north Atlantic swordfish population between regions of intense reproduction and regions with sporadic seasonal or non-existent reproduction. In a study of swordfish spawning in the Atlantic (Arocha 2007), determination of spawning condition was inferred from a combination of techniques which included histological analysis, whole oocycte characteristics, whole oocycte size frequency distributions and relative gonad index (RGI). Classification of sexually mature females (> 150 cm lower jaw-fork length, LJFL) in spawning condition was based on the relative gonad index (RGI) when spawning was imminent and defined as $_{spawn}$ RGI (= 27.64). The subtropical area (13°–35°N) of the western North Atlantic as defined by Arocha (2007) was divided into three subareas (Atlantic, Gulf of Mexico, Straits of Florida) to determine possible differences in spawning activity. In this area, the mean RGI was high in December, March, April, September and October with peaks in February, May, June and August (Arocha 2007). These observations suggest an almost year round spawning cycle with peak seasons, but in different locations. The Atlantic subarea (ATL) is the area northeast and east of the Antillean Island chain, an area that includes the southern Sargasso Sea. In the ATL area, spawning females occurred from December to May (**Table 2**). Spawning in the western North Atlantic consists of 2 spawning groups proposed by Arocha (1997) and later confirmed by Govoni *et al.* (2003). The first is in open ocean waters south of the Sargasso Sea and east of the Lesser Antilles, and the second in waters relatively close to land masses and fast current systems like the Windward Passage and Straits of Florida/Gulf Stream.

Spawning females seem to prefer waters with temperatures of 24°-25° C at depths between 0 and 150 m (Arocha 1997). These are largely the oceanographic conditions found in the southern Sargasso Sea south of the STCZ. Historical collections of swordfish larvae, presumed to be a month old, were collected in the subtropical area at similar depths and temperatures (Govoni *et al.* 2000) to those of spawning females. Consequently, the absence of spawning females in the temperate area further north is most likely due to unsuitable conditions for swordfish larvae to survive.

A plot of the location of spawning swordfish females (**Figure 3**) collected over five years (1991-1995) by longline vessel observers indicates a concentration between 18°and 25°N (Arocha 2007). The relative consistency of the location of spawning females over this five year period suggests a strong association in relation to the STCZ.

White marlin
White marlin spend most of their time in the epipelagic zone in water 24°-29 °C and often associate with ocean fronts (ICCAT 2013). They are batch spawners, shedding batches of hydrated oocytes in separate spawning events (deSylva and Breder 1997). Based on macroscopic and microscopic gonad assessment of samples collected between 5°N and 25°N in the western Atlantic, Arocha and Marcano (2006) estimated that 50% of female white marlin are mature (*L*50) at 189.9 cm LJFL. More recently, Arocha and Bárrios (2009) determined the *L*50 for females at 160.5 cm LJFL, based on a larger number of samples (N = 1389) collected from the western central Atlantic. Documented white marlin spawning areas occur mainly in the tropical western North Atlantic, predominantly in the same offshore locations which they normally inhabit. In the western North Atlantic, seasonal spawning concentrations have been noted northeast of Hispaniola and Puerto Rico (Arocha and Bárrios 2009; Arocha and Marcano 2006), and off the east coast of Hispaniola (Prince *et al.* 2005). In this area, spawning occurs from April to July, with spawning activity peaking around April-May (Arocha and Bárrios 2009). The spawning of white marlin off Punta Cana, in the western part of the Mona Passage, is confirmed by the presence of a ripe female and the collection of very young larvae in the area (Prince *et al*. 2005), and effectively provides evidence of exact areas where white marlin spawn. A plot of the location of spawning white marlin in 2002-03 shows a concentration between 20º- 23º N (**Figure 3**) in the same area as both albacore tuna and swordfish. The presence of spawning white marlin in this area is not well understood but may be related to the oceanographic conditions (STCZ) that prevail in the spawning area during the first part of the year. Spawning females could benefit from the proximity to these oceanographic features by enhancing the probability that there will be sufficient food available for larvae and that the larvae may also be transported out of the area (Arocha and Bárrios 2009). Possible food sources for white marlin larvae as they develop within the spawning area may be leptocephali from Notacanthiformes and Anguilliformes. This is particularly true for larvae from *Anguilla anguilla* and *A. rostrata* which are known to spawn in February-May in the same area (McCleave 1993; McCleave *et al.* 1987) where white marlin spawning females were captured.

Additional spawning species

Blue marlin

Prince *et al*. (2005) conducted a concurrent electronic tagging and larval sampling program with a focus on white marlin in the vicinity of Mona Passage (off southeast Hispaniola), Dominican Republic, during April and May 2003. Larval sampling yielded 18 istiophorid larvae: eight were white marlin but four were blue marlin. This provides clear evidence of springtime spawning activity in this area (Punta Cana, DR) by both species. The presence of larvae is the most direct way of documenting that a spawning event has actually occurred and confirms that blue marlin are spawning near the southern edge of the Sargasso Sea. Moving further north into the Sargasso Sea, Luckhurst *et al.* (2006) provided documentation of blue marlin (*Makaira nigricans*) spawning in Bermuda (32º N.) in July when SST is 27°- 28º C. Based on a macroscopic and microscopic evaluation of gonads, seven of 10 specimens sampled in July were in spawning condition.

Wahoo

In a review of wahoo biology in the western Atlantic, Oxenford *et al.* (2003) provided information on spawning seasonality in Bermuda. The spawning season was from May to August based on a macroscopic assessment of female gonads. The presence of running ripe females (hydrated oocytes in the ovaries) was considered to be direct evidence of reproductive condition as spawning would be expected to occur within 24 hrs.

Porbeagle shark

Porbeagles are large, pelagic sharks restricted to cold, temperate waters. There is considerable knowledge of their reproductive biology - they reach sexual maturity at 13 yrs., the reproductive period is 1 year and average litter size is 4 (ICCAT 2008). However, their pupping (birthing) grounds had never been identified until a pop-up satellite archival tagging (PSAT) program was conducted off eastern Canada (Campana *et al.* 2010). A total of 21 sharks were tagged. All males and immature sharks remained on the continental shelf after tagging but all seven mature females with spring pop-up dates migrated up to 2,356 km through the winter, beneath the Gulf Stream to a subtropical pupping ground in the Sargasso Sea (Campana *et al.* 2010). The tags of six of the seven females popped up in April – early May in the southern Sargasso Sea (**Figure 2**). All tags popped-up south of 30º N. and four of the tags first reported at latitudes between 21º and 25º N. (Campana *et al.* 2010). Three of these tags popped up in the region of the STCZ. Given the energy expenditure to migrate such distances to give birth suggests that oceanographic conditions in the southern Sargasso Sea must be favorable for porbeagle sharks and may enhance the survival rates of newborn sharks.

ICCAT catch patterns and trends in the southern Sargasso Sea

The ICCAT CATDIS database provides estimates of nominal catches for the nine major tuna and tuna-like species managed by ICCAT. The data are stratified in time (trimester) and space (5x5 degree squares) and all longliner catch data are reported on this spatial scale. In order to evaluate the importance of the Sargasso Sea to ICCAT longline fisheries, Luckhurst (2014c) analyzed reported catches of tunas and swordfish between latitude 25° and 40° N (**Figure 1**). Given the location of the STCZ in the southern Sargasso Sea, it was necessary to analyze the catch data from 20°- 25° N to evaluate the importance of this latitude zone. Data extractions were made for each of the three species of interest, namely, albacore tuna, swordfish and white marlin. The most recent 21 year period of data, i.e. 1992-2012 was used for albacore and swordfish while the analysis for white marlin, which is a by-catch species, was done for the latest 15 years (1998-2012). Within the Sargasso Sea Commission (SSC) study area, there are a total of 15 ICCAT reporting squares, 11 of which are exclusively in international waters (**Figure 5**). The exceptions are Bermuda's EEZ and the two squares (numbers 12 and 13, **Figure 5**) in the SW corner of the Sargasso Sea which include the EEZ of Turks and Caicos Islands, Dominican Republic, Puerto Rico, U.S.Virgin Islands, British Virgin Islands and Antigua and Barbuda.

Data extractions were made by quarter and year from the 15 reporting squares in the SSC Area. The annual catch total by square and year were summarized for albacore and swordfish for all 15 reporting squares. These detailed catch figures by square enable latitude band comparisons within the Sargasso Sea. In addition, an analysis of the swordfish catch data were made by quarter allowing an evaluation of the seasonality of catches. However, data extractions for white marlin were only made for the southern half of the Sargasso Sea (20°-30°N), i.e. squares 8-15 (**Figure 5**).

Albacore tuna

An analysis of the catch data for albacore from the Sargasso Sea from 1992 – 2012 shows that the total annual catch from the southern Sargasso Sea (20º - 30º N) ranged from 22.18 mt in 1995 to 1437 mt in 2001 (**Table 3**). These catches comprised 1.1% and 36.2% respectively of the total annual catch from the Sargasso Sea. The mean annual catch from the southern Sargasso Sea over the 21 year period of the analysis was 427.6 mt compared with 2563.7 mt for the entire Sargasso Sea indicating that the average annual catch from the southern zone was only 16.7% of the Sargasso Sea total (**Table 3**). In most years, the catches from the latitude band (20°-25º N) were greater than those from 25°- 30º N (**Table 3**). Although there is no clear pattern, it appears as if there is a preponderance of the annual catch in the southern zone in the second trimester (the main spawning period for albacore was April) followed by the third trimester.

Swordfish

The catch data for swordfish from 1992 – 2012 indicates that the total annual catch from the latitude band 20°-30° N in the Sargasso Sea varied significantly from 270.8 mt in 1994 to 4.6 mt in 2000 (**Table 4**). The percentage of the total annual catch from the Sargasso Sea represented by this same latitude band ranged from 94.1% in 1992 to 4.2% in 2000 (**Table 4**). These percentage values should be treated with caution as they are strongly influenced by the size of the reported catch in a given year. The mean annual catch from the latitude band 20°-30° N over the 21 year period was 109.5 mt compared with 322.2 mt for the entire Sargasso Sea. The average annual percentage catch from the latitude band 20°- 30° N compared to the Sargasso Sea as a whole was 34% (**Table 4**). From 2007 onward, the annual catch contribution from the latitude band 25°-30° N has shown little variation (range 9.7% to 16.7%) suggesting a reduction in fishing effort for swordfish in this band. In the first half of the catch series, the southern zone (20°-25º N) had larger catches than the 25°-30º N band but from 2002-2012 the pattern was reversed (**Table 4**). The seasonality of catch by trimester in the southern zone indicates that the largest catches were taken in the first trimester (**Table 5**) with a mean of 55.5% of the annual total followed by the second trimester at 23.5% of annual. Catches in the third trimester were very low and then started increasing again in the fourth trimester (**Table 5**). Total annual catch in the southern zone (20°-25º N) declined dramatically after 1998 and averaged < 9 mt from 1999 to 2012 (**Table 5**).

White marlin

As stated above, data extractions were only made for the southern Sargasso Sea in the latitude band from 20º to 30º N. The catch levels from 1998-2006 ranged from 6.71 to 53.37 mt with the majority of the catch coming from the most southerly band, i.e. 20º to 25º N (**Table 6**). However, catch levels in this band declined substantially from 2007-2012 and ranged from 0.37-7.08 mt. In four of these years, the catch level was < 1 mt (**Table 6**) and overall there were few reported catches in the southern most latitude band. It is not possible to determine the reason for this significant decline in white marlin by-catch in the most recent years but it may be related to changes in fishing area and effort by longline fleets.

Discussion

The data presented here indicate the importance of the southern Sargasso Sea as a spawning area for three of the principal species managed by ICCAT. The overlap in the spawning areas of the species during the spring months and the proximity to the STCZ provide convincing evidence of the significance of this zone. Although spawning is known to occur in other areas of the western Atlantic for all three species, the spatial and seasonal components of this area suggest that it may have particular significance. The consistency of the presence of spawning fish over a number of years in the same area, e.g. albacore, indicates a strong association with the oceanographic features, i.e. STCZ, that occur there on a predictable basis. Although there are no data available, it may be that spawning success is enhanced when favorable conditions occur predictably in time and space and the species concerned possess the physiological abilities to orient to them. The presence of oceanographic features such as the STCZ can have significant effects on fishery performance, e.g. the Hawaiian swordfish longline fleet centers its fishing effort from January to May near a Subtropical Frontal Zone in the North Pacific (Seki *et al.* 2002). The seasonal dynamics of this oceanographic feature appear to be similar to the Atlantic STCZ and are located in a similar latitude band, i.e. 28°-34° N (Seki *et al.* 2002).

The association of other species with the STCZ area during the same time period may infer that there are also reproductive advantages for other taxa. For example, the leptocephali of the anguillid eels *Anguilla anguilla* and *A. rostrata* which are known to spawn in February–May (McCleave 1993; McCleave *et al.* 1987) are found over a large area of the southern Sargasso Sea but a portion of the defined larval distribution (**Figure 4**) overlaps with the spawning area of the three principal species which are the main subject of this paper. The early stage larvae of both white marlin and blue marlin were found near the Mona Passage in April-May (Prince *et al.* 2005) indicating that this is a spawning area for both species. Given the importance of protecting spawning stocks, the authors indicated that protection of this potentially important white marlin spawning ground seemed warranted, at least until further studies could be conducted on the temporal and spatial extent of spawning and associated adult movement (Prince *et al.* 2005). Further north at Bermuda's latitude (32º N) in the middle of the Sargasso Sea, blue marlin are known to spawn in July (Luckhurst *et al.* 2006), presumably as they migrate northward in the Sargasso Sea as SST warms (Luckhurst, 2014a).

The importance of the Sargasso Sea to the reproductive cycle of porbeagle sharks was unknown until the recent discovery of a pupping ground in the southern part (Campana *et al.* 2010). This finding suggests that the selective advantage of sharks migrating over 2,000 km from the continental shelf of Canada to give birth in the southern Sargasso Sea must be considerable. However, the pupping grounds are in international waters and thus subject to little regulation which could compromise management programs of the stock in the EEZ of other countries, particularly Canada where the main fishery is based (Campana *et al.* 2010).

When remarking on the importance of fronts and eddies, Owen (1981) wrote "We see that on every scale of frontal and eddy activity in the-open sea, there are examples of ecologically significant effects operating through food web stability, community structure, local population dynamics, phytoplankton production and standing stocks, etc.". In a catalog of effects of fronts and eddies, Owen (1981) listed amongst a number of ecological effects the following: attract and sustain large motile animals, serve as reproduction refuges, act as faunal boundaries and modify migration patterns of annual fish movements. Using a binomial generalized linear model fit to oceanographic variables, Schick *et al.* (2004) found that bluefin tuna were seen closer to SST fronts than locations in which no tuna were seen. However, the spatial relationship between bluefin tuna and SST fronts was inconsistent suggesting that other factors, such as prey density, may be important predictors of bluefin distribution in the Gulf of Maine. Head *et al.* (2002) found differences in groups of phytoplankton in relation to the Azores Front although the front was a zone of low production. Amongst other planktonic groups it appeared to form a faunal boundary. Some of the ecological effects of fronts and eddies appear to be consistent with those found in the STCZ in the southern Sargasso Sea. Along the STCZ frontal zone, frontal jets or eastward counter currents can form and transport larvae (fish, eel leptocephali) from the spawning area eastward further offshore into the Sargasso Sea (Laffoley *et al*. 2011). This may be a significant dispersal mechanism from the spawning area but does not appear to have been much studied.

When considering possible management options with respect to the protection of spawning stocks, a time/area closure is one of the management options. Closing areas where adult fishes, potential spawners, are caught by fisheries, a time/area closure should allow for a significant and immediate reduction of fishing mortality on the adult fraction of the stocks, thus producing a positive effect on the sizes of spawning stocks (Fonteneau 2007). If the spawning area and seasonality of a given stock are well-defined then a time/area closure may be the best option for protecting the stock during this critical life history phase. Seasonal closures of spawning areas for tuna species should be positive and effective because post-spawning tunas usually do not stay in the spawning zone, e.g. bluefin tuna (Fonteneau 2007). Our data for albacore tuna spawning in the southern Sargasso Sea may indicate similar behavior as all of the albacore sampled in May appeared to be post-spawn (**Table 1**). ICCAT has previously recognized the benefits of creating a time/area closure. Such a time/area closure for two months (Jan.-Feb.) is in effect for purse-seine fleets using FADs who are fishing for bigeye and yellowfin tunas in the Gulf of Guinea (ICCAT 2014). This management measure is in place to reduce fishing mortality on juvenile tunas taken by purse-seine vessels thus potentially increasing the size of the spawning stocks as more fish are left to grow to maturity.

In view of the fact that the white marlin stock is considered overfished (ICCAT 2014) it would seem prudent to consider seasonal protection for an identified spawning area such as the southern Sargasso Sea. The fact that this area is a multi-species spawning area suggests that it must be of considerable biological significance to at least the three ICCAT-managed species presented here and possibly other species. Prince *et al.* (2005) have shown that blue marlin, which is also considered to be an overfished stock (ICCAT 2014) are spawning in the vicinity of the southern Sargasso Sea. On the basis of the area catch analysis presented here, it appears that a time/area closure to protect this identified spawning area would benefit albacore tuna and swordfish stocks and would not likely have a significant impact on the overall catch of albacore and swordfish, both of which are ICCAT target species. It is more difficult to assess possible impacts on white marlin, which is a by-catch species, but the benefits to all three stocks of potentially increasing spawning output by seasonally protecting the southern Sargasso Sea without significantly reducing overall catches in the western North Atlantic should be considered.

Acknowledgements

The senior author (BL) wishes to acknowledge the support of the Sargasso Sea Commission (SSC) in the production of this paper.

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Table 1. Spawning seasonality of albacore tuna in the southern Sargasso Sea based on opportunistic sampling of the Venezuelan longline fleet (1995-2003). No samples were available from September to January. Total number of spawning fish (n = 894); total sample size (N=18,202). Spawning fish were only documented in March and April (Arocha, unpublished data).

	1995	*1996*	*1997*		*1998*		*2000*	*2001*		*2002*		*2003*	
	No spawn	*No spawn*	*Spawn*	*No spawn*	*Spawn*	*No spawn*	*No spawn*	*Spawn*	*No spawn*	*Spawn*	*No spawn*	*Spawn*	*No spawn*
Feb.									180				
Mar.					**38**			**169**		**31**			
Apr.			**369**		**62**					**87**		**138**	
May	765			1262		48	70				847		806
Jun.	1989	780		1625		146	747				606		663
Jul.	2400	1048		1173		168	462				259		839
Aug.	422						3						
Total	5576	1828	**369**	4060	**100**	362	1282	**169**	180	**118**	1712	**138**	2308

Table 2. Total number of female swordfish (*n*; > 150 cm lower jaw-fork length) and number of spawning females (SF) during the spawning season in the Atlantic subarea (ATL) of the western North Atlantic which includes the southern Sargasso Sea (from Arocha, 2007).

Month	**n**	**SF**
December	46	9
January	120	32
February	74	30
March	9	-
April	13	4
May	42	13
June	-	-
Total	**304**	**88**

Table 3 A- ICCAT Albacore Tuna Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes)

Only countries with 5% or greater of the annual catch in the Sargasso Sea in a given year are included in the analysis. All catches in metric tons(mt).

		1992		**1993**		**1994**		**1995**		**1996**		**1997**		**1998**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
1	35°- 40°N	3.51		0.62		8.55		0		0		0		0	
2	35°- 40°N	0.23		0		120.50		0		0		0		0	
3	35°- 40°N	4.89	8.62	49.70	50.32	43.18	172.23	0	0	0	0	0	0	0	0
4	30°- 35° N	0		1.13		0.00		177.17		548.70		293.04		36.21	
5	30°- 35° N	0.02		0.46		12.21		183.14		119.37		15.80		127.33	
6	30°- 35° N	3.76		0		151.15		194.60		797.21		584.57		193.52	
7	30°- 35° N	2.09	5.88	0	1.59	254.99	418.35	122.88	677.79	417.73	1883.00	437.57	1330.98	336.84	693.91
8	25°- 30°N	2.67		15.72		0		0		0		9.91		0	
9	25°- 30°N	0.24		0.67		0		0		0		0		0	
10	25°- 30°N	0		0.02		0		0		43.44		0		0.88	
11	25°- 30°N	0	2.91	0	16.42	0	0	0	0	0.00	43.44	0	9.91	35.37	36.25
12	20°- 25°N	44.32		0.69		14.43		0		0		0.06		90.42	
13	20°- 25°N	9.95		0.21		16.89		4.31		0.55		0.17		143.62	
14	20°- 25°N	51.90		1.22		2.53		1.71		14.20		89.05		46.92	
15	20°- 25°N	0	106.16	244.74	246.86	0.27	34.11	16.16	22.18	31.52	46.27	0.49	89.77	113.27	394.22
Total Catch - Sargasso Sea			123.58		315.20		624.69		699.97		1972.71		1430.66		1124.38
% Total catch - 25°- 30°N			2.36%		5.21%		0.00%		0.00%		2.20%		0.69%		3.22%
% Total catch - 20°- 25°N			85.91%		78.32%		5.46%		3.17%		2.35%		6.27%		35.06%

Table 3 B- ICCAT Albacore Tuna Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes). All catches in metric tons (mt).															
		1999		**2000**		**2001**		**2002**		**2003**		**2004**		**2005**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
1	35°- 40°N	109.00		0		33.95		137.84		109.65		0		18.80	
2	35°- 40°N	40.08		0		49.59		47.62		67.79		0		39.04	
3	35°- 40°N	0	149.08	0	0	30.80	114.33	2.59	188.05	7.58	185.02	0	0	7.00	64.83
4	30°- 35° N	364.27		342.23		282.95		436.63		32.58		53.34		128.35	
5	30°- 35° N	200.97		276.93		193.96		337.12		131.43		70.61		101.24	
6	30°- 35° N	343.70		92.76		291.10		245.78		272.87		401.70		178.46	
7	30°- 35° N	330.88	1239.83	74.56	786.48	150.73	918.74	259.66	1279.19	155.92	592.80	141.05	666.70	182.91	590.96
8	25°- 30°N	125.15		343.87		384.08		193.40		47.72		109.42		12.32	
9	25°- 30°N	76.10		35.77		87.52		44.09		87.50		115.00		40.73	
10	25°- 30°N	42.52		7.77		63.52		61.61		87.14		61.82		12.00	
11	25°- 30°N	35.98	279.75	15.35	402.76	106.85	641.98	63.14	362.25	69.35	291.71	35.75	321.99	29.54	94.59
12	20°- 25°N	330.16		153.35		194.48		68.22		0.24		49.40		49.40	
13	20°- 25°N	172.14		90.46		326.56		225.95		126.41		66.47		66.47	
14	20°- 25°N	88.91		143.68		195.62		101.03		32.20		191.97		191.97	
15	20°- 25°N	110.36	701.56	71.92	459.42	78.45	795.11	32.01	427.21	80.79	239.64	215.76	523.59	215.76	523.59
Total Catch - Sargasso Sea			2370.22		1648.66		2470.16		2256.70		1309.16		1512.29		1273.99
% Total catch - 25°- 30°N			11.80%		24.43%		25.99%		16.05%		22.28%		21.29%		7.43%
% Total catch - 20°- 25°N			29.60%		27.87%		32.19%		18.93%		18.30%		34.62%		41.10%

Table 3 C- ICCAT Albacore Tuna Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes). All catches in metric tons(mt).

		2006		**2007**		**2008**		**2009**		**2010**		**2011**		**2012**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
1	35°- 40°N	44.74		0		0		0		0		0		0	
2	35°- 40°N	0.17		0		0		0		0		0		0	
3	35°- 40°N	0.02	44.93	0	0	0	0	9.70	9.70	0.00	0.00	0	0	0	0
4	30°- 35° N	111.49		0		0		1.85		47.41		19.5		47.82	
5	30°- 35° N	39.54		0		10.98		11.87		14.05		1.06		2.54	
6	30°- 35° N	107.94		15.90		102.46		31.18		7.35		20.15		166.46	
7	30°- 35° N	29.06	288.02	34.32	50.21	47.21	160.65	44.03	88.93	5.79	74.59	15.52	56.23	75.70	292.53
8	25°- 30°N	74.23		9.15		0		3.73		42.36		37.59		38.22	
9	25°- 30°N	25.81		0.66		8.27		3.21		90.01		67.06		80.29	
10	25°- 30°N	28.71		0.12		23.37		2.93		55.54		82.8		27.82	
11	25°- 30°N	8.94	137.69	0	9.92	41.50	73.14	3.98	13.84	36.66	224.57	64.37	251.82	7.19	153.53
12	20°- 25°N	0.09		64.44		0.12		33.29		41.44		52.80		27.77	
13	20°- 25°N	25.11		84.43		2.08		8.67		54.46		68.51		36.05	
14	20°- 25°N	44.40		100.71		3.93		47.04		21.50		91.06		20.68	
15	20°- 25°N	69.30	138.89	23.97	273.54	12.40	18.53	39.49	128.49	41.03	158.44	89.55	301.92	2.90	87.41
Total Catch - Sargasso Sea			609.53		333.68		252.33		240.96		457.61		609.97		533.47
% Total catch - 25°- 30°N			22.59%		2.97%		28.99%		5.74%		49.08%		41.28%		28.78%
% Total catch - 20°- 25°N			22.79%		81.98%		7.34%		53.32%		34.62%		49.50%		16.39%

Table 4 A- ICCAT Swordfish Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes)

Only countries with 5% or greater of the annual catch in the Sargasso Sea in a given year are included in the analysis. All catches in metric tons(mt).

		1992		**1993**		**1994**		**1995**		**1996**		**1997**		**1998**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
1	35°- 40°N	3.37		7.54		0		0.69		8.06		1.01		55.12	
2	35°- 40°N	0		0.07		0.38		0.46		3.57		7.10		1.09	
3	35°- 40°N	2.76	6.13	0.39	8.00	19.98	20.36	1.07	2.21	0	11.63	5.19	13.31	12.90	69.11
4	30°- 35° N	2.53		6.12		0.31		0.08		0		1.90		0.82	
5	30°- 35° N	1.10		1.57		1.15		0		1.00		5.70		2.39	
6	30°- 35° N	1.27		0		2.47		7.32		1.75		2.05		4.08	
7	30°- 35° N	2.61	7.52	0	7.70	8.09	12.02	0.38	7.78	0.07	2.82	1.75	11.40	7.91	15.19
8	25°- 30°N	32.99		85.59		98.07		7.25		0		6.03		0	
9	25°- 30°N	6.82		15.81		1.77		0		0		8.06		0	
10	25°- 30°N	0.06		2.16		1.23		4.04		0		3.58		0.10	
11	25°- 30°N	0	39.87	0	103.56	0	101.07	0	11.29	0	0	0	17.66	0.84	0.94
12	20°- 25°N	8.18		4.13		0.69		1.07		0.32		1.79		0.37	
13	20°- 25°N	88.50		31.81		15.29		11.16		14.06		7.64		5.44	
14	20°- 25°N	81.52		89.65		126.04		42.27		66.73		55.50		115.13	
15	20°- 25°N	0	178.21	20.35	145.94	27.67	169.70	45.68	100.18	28.52	109.63	22.74	87.66	29.14	150.08
Total Catch - Sargasso Sea			231.72		265.20		303.15		121.46		124.07		130.04		235.32
% Total catch - 25°- 30°N			17.21%		39.05%		33.34%		9.30%		0		13.58%		0.40%
% Total catch - 20°- 25°N			76.91%		55.0%		56.0%		82.5%		88.4%		67.4%		63.8%

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Table 4 B- ICCAT Swordfish Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes). All catches in metric tons (mt).

		1999		2000		2001		2002		2003		2004		2005	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
1	35°- 40°N	2.23		0		0.46		1.42		2.04		0.93		4.03	
2	35°- 40°N	0.20		17.96		19.24		0.22		15.44		33.22		43.91	
3	35°- 40°N	23.13	25.56	60.64	78.60	104.29	123.98	64.06	65.69	179.06	196.54	102.66	136.82	55.58	103.53
4	30°- 35° N	0.25		0		0		1.08		0.90		1.86		0.52	
5	30°- 35° N	3.38		0		0		2.96		9.86		6.91		9.40	
6	30°- 35° N	14.43		13.72		26.74		4.27		71.15		17.67		16.16	
7	30°- 35° N	16.10	34.16	13.14	26.86	13.05	39.79	16.98	25.29	43.44	125.35	21.83	48.26	15.23	41.32
8	25°- 30°N	9.33		0		0.79		57.50		38.62		53.26		57.10	
9	25°- 30°N	0.71		0		0.17		32.08		32.43		63.66		20.25	
10	25°- 30°N	0.67		0		0.42		0.91		1.35		3.00		3.83	
11	25°- 30°N	1.32	12.02	0	0	0.33	1.70	3.39	93.88	2.80	75.21	6.12	126.04	8.81	90.00
12	20°- 25°N	2.06		0		0.83		1.43		4.33		13.76		5.36	
13	20°- 25°N	0.86		0		6.15		1.39		0.07		1.63		5.93	
14	20°- 25°N	10.54		2.66		0.40		0.62		0.82		0		3.29	
15	20°- 25°N	14.67	28.13	1.94	4.60	0.54	7.91	3.53	6.96	0.50	5.73	0	15.39	1.96	16.55
Total Catch - Sargasso Sea			99.88		110.06		173.39		191.83		402.83		326.50		251.40
% Total catch - 25°- 30°N			12.03%		0		0.98%		48.94%		18.67%		38.60%		35.80%
% Total catch - 20°- 25°N			28.2%		4.2%		4.6%		3.6%		1.4%		4.7%		6.6%

Table 4 C- ICCAT Swordfish Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes). All catches in metric tons (mt).

		2006		**2007**		**2008**		**2009**		**2010**		**2011**		**2012**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
1	35°- 40°N	6.43		0.42		34.96		0.66		0		0		0	
2	35°- 40°N	25.79		0.37		82.93		20.39		16.57		60.40		44.62	
3	35°- 40°N	196.46	228.68	209.19	209.98	321.29	439.18	202.03	223.09	165.89	182.46	197.84	258.24	275.84	320.46
4	30°- 35° N	0		9.09		1.31		0		0		0		0	
5	30°- 35° N	2.85		1.20		0		0		0		0		0	
6	30°- 35° N	7.18		2.24		22.10		0		0		3.65		36.17	
7	30°- 35° N	101.42	111.45	207.56	220.10	56.96	80.37	164.90	164.90	201.88	201.88	402.41	406.07	117.13	153.30
8	25°- 30°N	82.22		43.85		47.85		38.38		72.35		118.59		77.22	
9	25°- 30°N	52.91		3.70		10.41		0		0		0.02		4.23	
10	25°- 30°N	5.39		0		0.44		0		0		0.17		0	
11	25°- 30°N	2.38	142.90	0	47.55	0	58.70	0	38.38	0	72.35	0.00	118.79	0	81.45
12	20°- 25°N	2.38		0.85		2.61		0.46		1.02		7.02		0.44	
13	20°- 25°N	1.22		2.40		0.70		0.58		2.39		1.20		1.44	
14	20°- 25°N	1.29		0.84		0		1.01		1.13		1.72		0.92	
15	20°- 25°N	4.06	8.96	0	4.08	0	3.31	1.03	3.07	0.14	4.68	2.36	12.31	0	2.80
Total Catch - Sargasso Sea			491.98		481.71		581.56		429.44		461.37		795.40		558.00
% Total catch - 25°- 30°N			29.05%		9.87%		10.09%		8.94%		15.68%		14.93%		14.60%
% Total catch - 20°- 25°N			1.8%		0.8%		0.6%		0.7%		1.0%		1.5%		0.5%

Table 5 - Summary of annual swordfish catch total by trimester from the ICCAT CATDIS database from 1992 – 2012 for the southern zone of the Sargasso Sea (**20°-25° N**). Note large decline in annual catch after 1998.

	Trimester 1		**Trimester 2**		**Trimester 3**		**Trimester 4**		**Total Annual**
Year	**Catch - mt**	**% of Annual**	**Catch - mt**	**% of Annual**	**Catch - mt**	**% of Annual**	**Catch - mt**	**% of Annual**	**Catch**
1992	157.27	88.25%	1.33	0.75%	0.26	0.15%	19.35	10.86%	178.21
1993	134.84	92.39%	0	0	0.22	0.15%	10.89	7.46%	145.94
1994	103.29	60.87%	0.46	0.27%	0	0	65.94	38.86%	169.70
1995	97.66	97.49%	2.52	2.51%	0	0	0	0	100.18
1996	99.62	90.69%	0.22	0.20%	0	0	10.01	9.11%	109.84
1997	48.52	55.34%	0	0	0	0	39.15	44.66%	87.66
1998	71.65	47.63%	3.96	2.63%	2.57	1.71%	72.26	48.03%	150.43
1999	3.21	11.34%	2.38	8.43%	0.00	0	22.68	80.23%	28.27
2000	2.56	55.59%	0	0	0.06	1.28%	1.98	43.13%	4.60
2001	7.35	91.68%	0.10	1.30%	0.02	0.29%	0.54	6.73%	8.02
2002	3.26	45.58%	2.33	32.57%	1.08	15.01%	0.49	6.83%	7.16
2003	5.62	98.19%	0.03	0.53%	0.07	1.29%	0.00	0	5.73
2004	10.95	68.59%	1.30	8.14%	0.23	1.44%	3.48	21.83%	15.97
2005	9.88	59.47%	6.53	39.33%	0.07	0.40%	0.13	0.80%	16.61
2006	4.18	46.62%	3.34	37.29%	0.13	1.41%	1.32	14.69%	8.96
2007	0.33	8.15%	2.85	69.80%	0.53	12.88%	0.37	9.17%	4.08
2008	3.31	100%	0	0	0	0	0	0	3.31
2009	0.46	14.90%	2.15	69.91%	0.47	15.19%	0	0	3.07
2010	0	0	4.41	94.25%	0.27	5.75%	0	0	4.68
2011	4.06	33.00%	3.80	30.84%	0.97	7.88%	3.48	28.28%	12.31
2012	0	0	2.66	95.06%	0.14	4.94%	0	0	2.80
Mean		55.51%		23.51%		3.32%		17.65%	

Table 6 - ICCAT White Marlin Catch Area Analysis by latitude in Sargasso Sea (see Fig. 5 for area codes)

Only countries with 5% or greater of the annual catch in the Sargasso Sea in a given year are included in the analysis. All catches in metric tons(mt).

		1998		**1999**		**2000**		**2001**		**2002**		**2003**		**2004**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
8	25°- 30°N	0		5.25		0		3.12		0.51		0.72		0.81	
9	25°- 30°N	0.38		2.63		0		2.91		1.11		1.56		5.48	
10	25°- 30°N	0.57		1.79		0		0.63		0.17		2.94		0.05	
11	25°- 30°N	0.58	1.53	1.08	10.75	0.20	0.20	0	6.67	0.13	1.92	0	5.23	0	6.34
12	20°- 25°N	0		19.08		2.27		0.23		0.55		0.04		0.49	
13	20°- 25°N	0.50		21.24		0.71		2.94		4.25		13.54		0	
14	20°- 25°N	2.82		2.31		4.18		1.24		0		0.12		0	
15	20°- 25°N	6.72	10.04	0	42.62	3.06	10.22	2.53	6.93	0.08	4.88	0	13.70	1.37	1.86
Total Catch - Sargasso Sea			11.56		53.37		10.42		13.60		6.71		18.93		8.20
% Total catch - 25°- 30°N			13.2%		20.1%		2.0%		49.0%		28.6%		27.6%		77.4%
% Total catch - 20°- 25°N			86.8%		79.9%		98.0%		51.0%		72.7%		72.4%		22.6%

		2005		**2006**		**2007**		**2008**		**2009**		**2010**		**2011**		**2012**	
Area Code	Latitude band	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total	Catch	Band total
8	25°- 30°N	0.55		3.30		0.34		0.23		0.12		0.76		2.62		0.70	
9	25°- 30°N	0.35		2.59		0.03		0.01		0		0		0.19		0.07	
10	25°- 30°N	0.09		0.12		0		0		0		0		0		0	
11	25°- 30°N	0.16	1.16	0.05	6.06	0	0.37	0	0.24	0	0.12	0	0.76	0	2.81	0	0.77
12	20°- 25°N	0.81		0.02		0		0.06		6.78		0		0		0	
13	20°- 25°N	0.82		0.51		0		0		0.16		0		0		0	
14	20°- 25°N	0.26		0.65		0		0.14		0		0		0		0	
15	20°- 25°N	3.84	5.74	2.82	4.00	0	0	0	0.21	0.02	6.96	0	0	0	0	0	0
Total Catch - Sargasso Sea			6.90		10.06		0.37		0.45		7.08		0.76		2.81		0.77
% Total catch - 25°- 30°N			16.9%		60.2%		100.0%		54.0%		1.7%		100.0%		100.0%		100.0%
% Total catch - 20°- 25°N			83.1%		39.8%		0		46.0%		98.3%		0		0		0

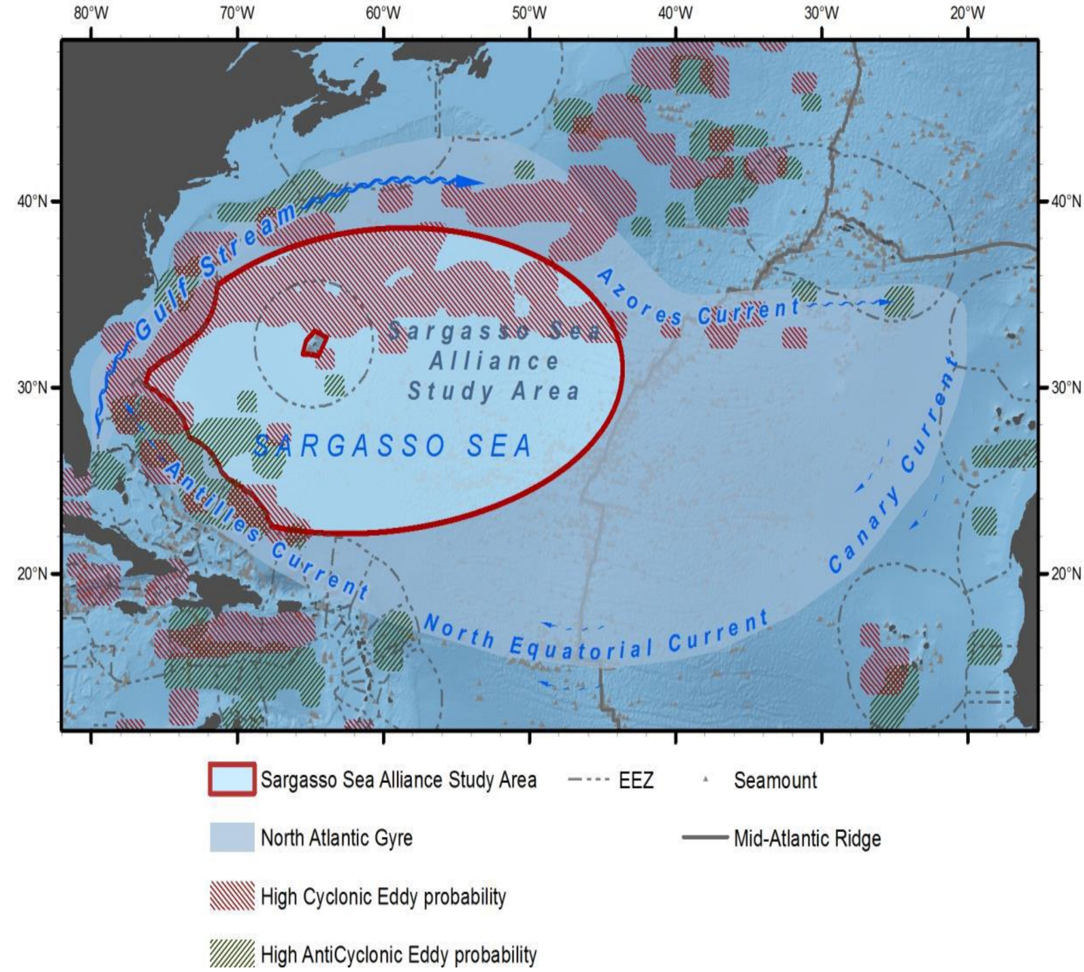

Figure 1. Map of the Sargasso Sea Alliance Study Area, including some of the major oceanographic features that influence overall boundary definition and location (from Laffoley *et al*. 2011).

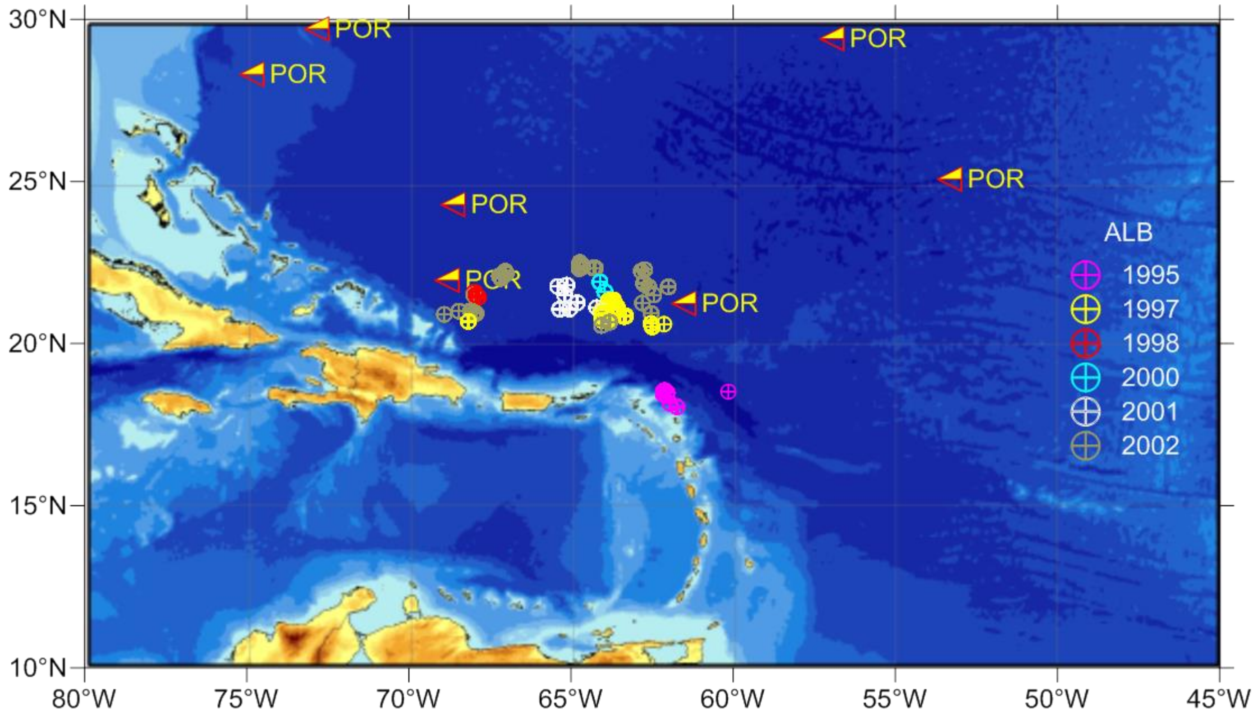

Figure 2. Location of spawning albacore tuna taken by Venezuelan longline vessels from 1995 – 2002. Total sample size of spawning fish across all years, N = 894. The POR symbols indicate the pop-up location of seven female Porbeagle sharks in a putative pupping ground in the southern Sargasso Sea. Five of the seven tags popped up in April. See text for details.

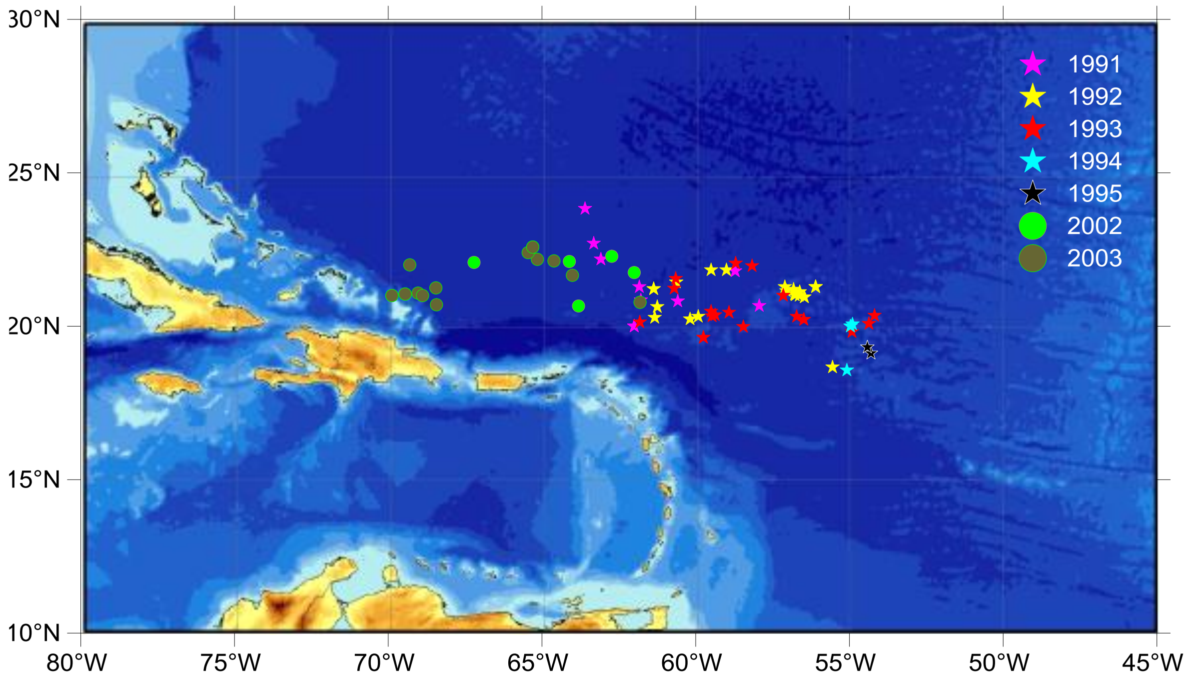

Figure 3. Location of spawning swordfish (stars, 1991-1995) and white marlin (filled circles, 2002-2003) taken by longline vessels in the southern Sargasso Sea. See text for details.

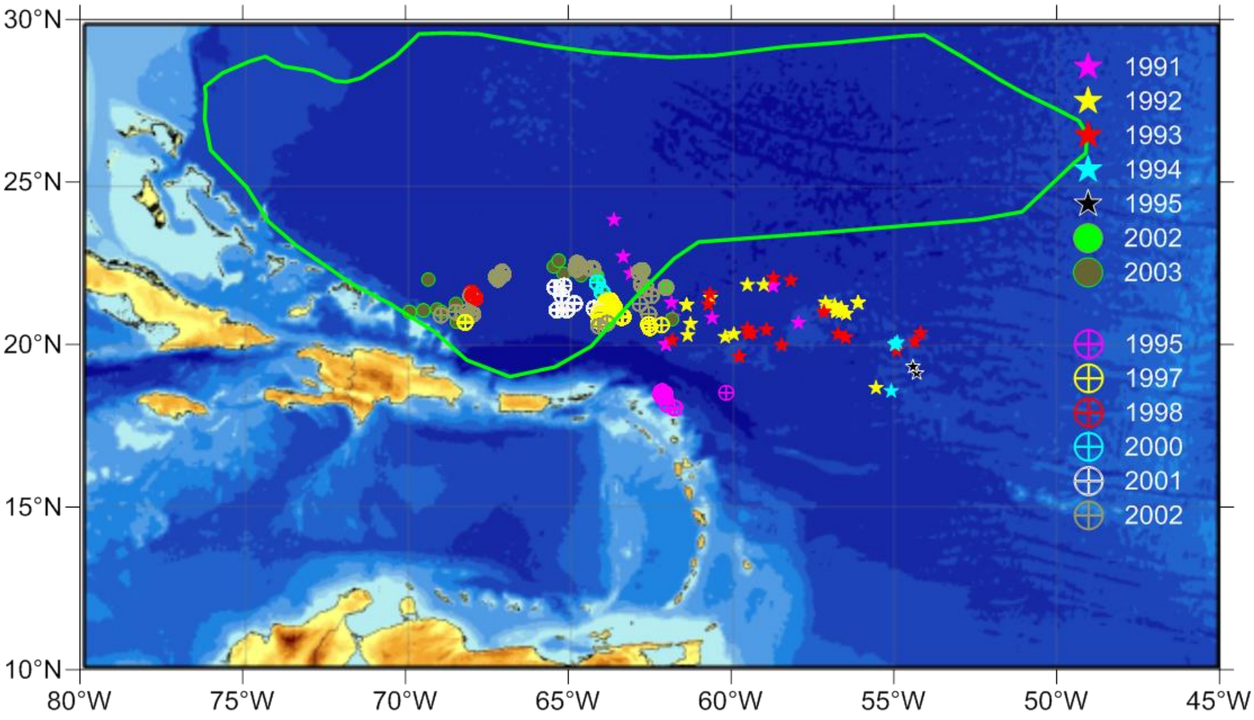

Figure 4. Composite showing location of spawning albacore (crossed circles), swordfish (stars) and white marlin (filled circles) in the southern Sargasso Sea. Polygon represents the area within which anguillid eel leptocephali have been collected. See text for details.

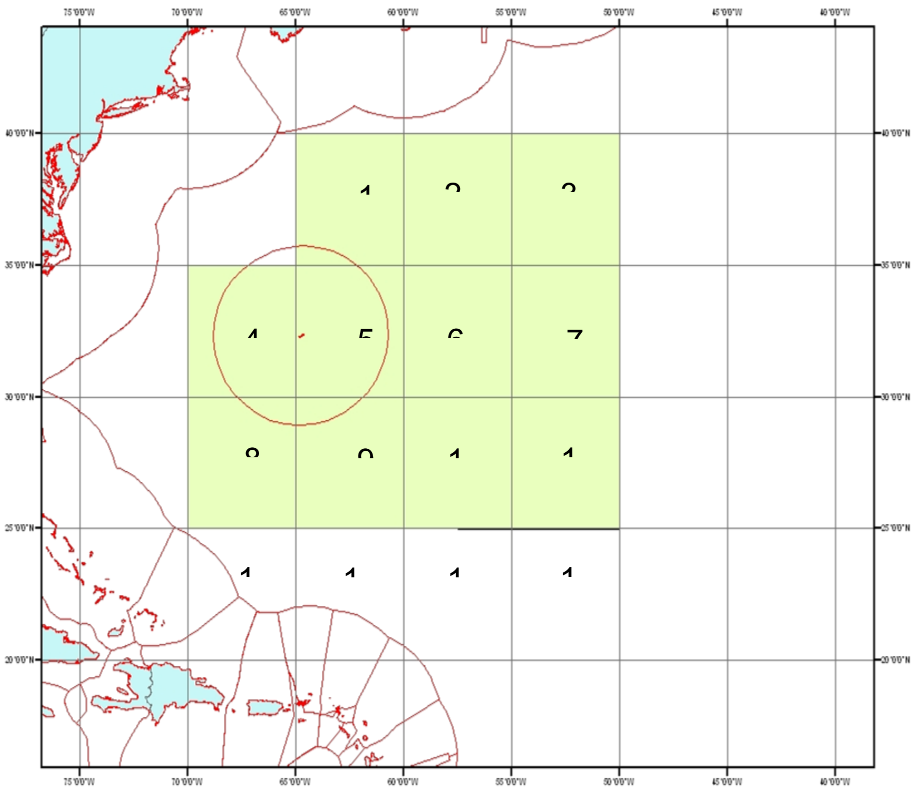

Figure 5. Sargasso Sea with ICCAT 5x5 degree reporting squares used for extracting catch data from the ICCAT CATDIS database. The circle around Bermuda delineates the Exclusive Economic Zone (EEZ) as do the lines projecting outward from the coastal states which border the Sargasso Sea.