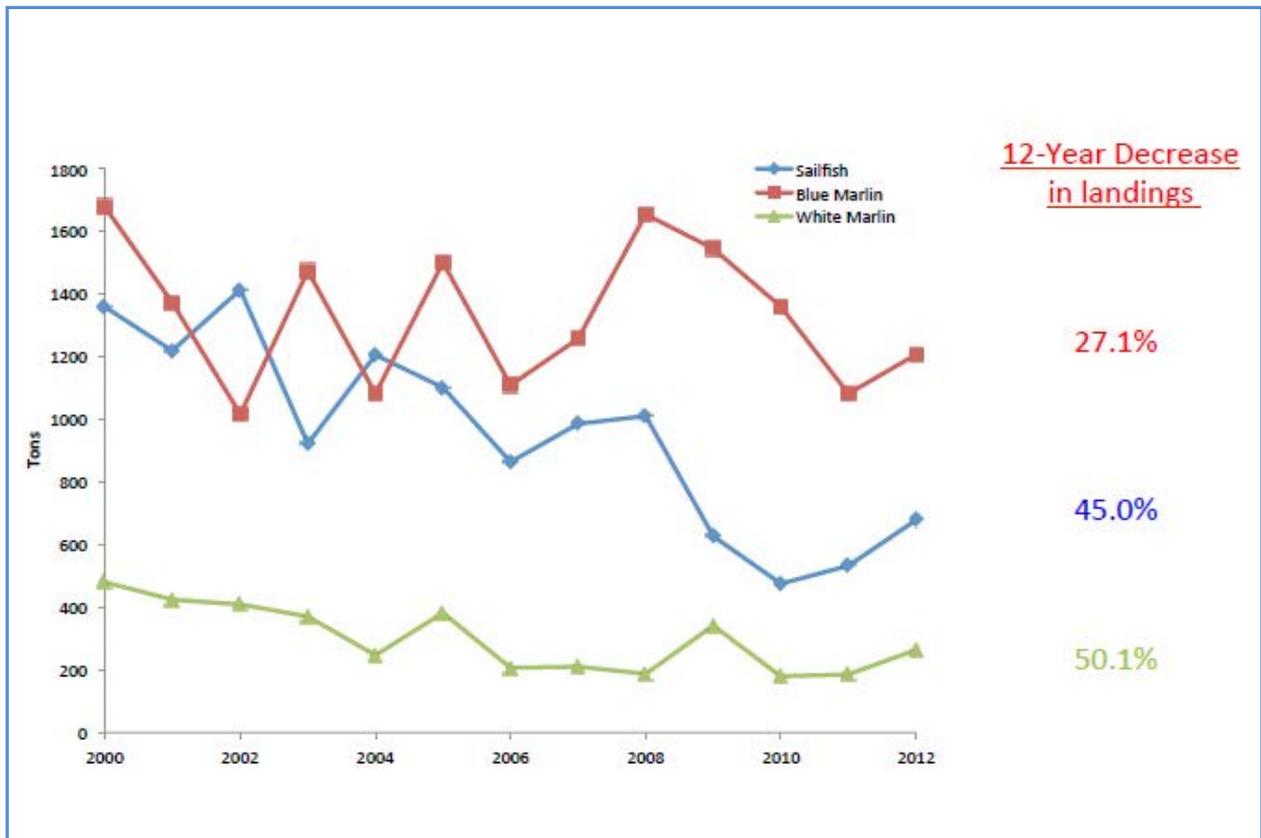




## STATUS OF BILLFISH RESOURCES AND BILLFISH FISHERIES IN THE WESTERN CENTRAL ATLANTIC



Source: ICCAT (2015)

## **STATUS OF BILLFISH RESOURCES AND BILLFISH FISHERIES IN THE WESTERN CENTRAL ATLANTIC**

by

**Nelson Ehrhardt and Mark Fitchett**  
School of Marine and Atmospheric Science,  
University of Miami  
Miami, United States of America

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ISBN 978-92-5-109436-5

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## **PREPARATION OF THIS DOCUMENT**

This document is part of a series of desk and field studies carried out under “Component 1. Generating value and conservation outcomes through innovative mechanisms” of the Caribbean Billfish Project GCP/ SLC/ 001/ WBK of the Ocean Partnership Program belonging to the Areas Beyond National Jurisdictions (ABNJ) program. The project is funded by the Global Environmental Facility (GEF) and The World Bank and executed by the Western Central Atlantic Fisheries Commission (WECAFC) of the Food and Agriculture Organization of the United Nations (FAO) based at the FAO Subregional Office in Bridgetown, Barbados.

The study was carried out under a contract with the International Game Fish Association (IGFA) through a Letter of Agreement with FAO. Support and guidance were provided by Mr Raymon van Anrooy, Secretary of the Western Central Atlantic Fishery Commission (WECAFC) and Mr Manuel Perez Moreno, Regional Project Coordinator, during the elaboration of the report

The preliminary findings of the study were presented at the 2<sup>nd</sup> Regional Workshop on Caribbean Billfish Management and Conservation of the WECAFC Recreational Fisheries Working Group held in November, 2015 in Panama City, Panama. In addition, the document was also reviewed by the members of the Consortium on Billfish Management and Conservation (CBMC) established in the Caribbean Billfish project. The International Commission for the Conservation of the Atlantic Tuna (ICCAT) is the source of much of the statistical and stock assessment information presented in the report. Layout assistance was received from Ms Magda Morales.

**FAO. 2016.**

*Status of billfish resources and billfish fisheries in the Western Central Atlantic*, by Nelson Ehrhardt and Mark Fitchett. FAO Fisheries and Aquaculture Circular No. 1127. Bridgetown, Barbados.

### **ABSTRACT**

This desk review considered over 100 pertinent documents on the subject matter and 74 of them (Cited literature) were selected for their critical contents. Three main billfish species have been assessed by the International Commission for the Conservation of Atlantic Tunas (ICCAT): blue marlin, white marlin and sailfish. ICCAT is responsible for the statistical and biological data collected for billfish stock assessments and for the modeling approaches adopted to assess status of exploitation.

Billfish are caught as bycatch in large Atlantic tuna fisheries. They represent a mere 0.76 percent of the tuna landings and this characteristic represents a major hurdle to objectively collect statistical data for billfish stock assessments. This fact is reflected in the many issues, statistical difficulties and result controversies encountered by the ICCAT scientific group when assessing these stocks.

This review finds that billfish resources have been subjected to intense exploitation in the tuna and tuna like fisheries in the Atlantic Ocean for more than six decades, and as consequence billfish resources appear depleted, overfished and/or undergoing overfishing. The area of the WECAFC is critically important to the habitat domain of the billfish in the western Atlantic. Fishery developments targeting highly migratory species in the eastern Caribbean Sea have contributed to the exploitation of billfish, of which blue marlin is the most impacted. The introduction in the 1980s and 1990s of moored fish aggregating devices (mFADs) in the region has created interest in billfish landings but more importantly has created competition between two diverse sectors: commercial and recreational fisheries. Reduction of billfish relative abundance and the concomitant decrease in billfish trophy sizes are impacting the socially and economically important recreational fishing industries of the Caribbean while adding only marginal revenues to the commercial fisheries. Lately, issues concerning property rights of the aggregated fish have reached extraordinary competition among the two sectors (commercial and recreational fisheries) to the point that recreationally caught fish in areas where mFADs are located are retained by the commercial fishers, therefore recreational catch and release practices are voided. Such complex resources utilization matters are neither recorded nor reported in the stock assessment process, although these represent the most important conservation issue related to billfish resource utilization in the WECAFC region.

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## **ACKNOWLEDGEMENTS**

The authors would like to acknowledge the contributions received from the following persons in the implementation of this desk study:

Jason Schratwieser, Conservation Director of the IGFA

David Die, Chair of the Standing Committee on Research and Statistics (SCRS) for ICCAT

Rob Kramer, President of the IGFA

Manuel Perez, Coordinator of Caribbean Billfish Project GCP/SLC/001/WBK, FAO

Raymon van Anrooy, WECAFC Secretary, FAO

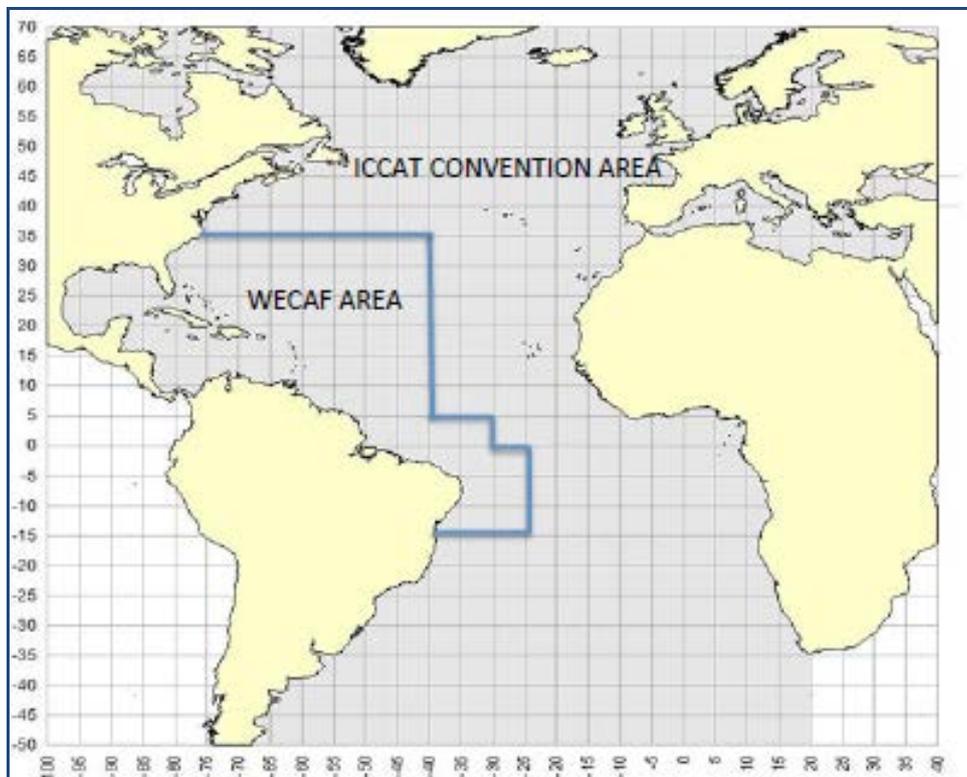
Freddy Arocha, Professor at the Universidad del Oriente, Cumana, Venezuela

## 1. INTRODUCTION

This report consists of a summary of findings for a desk study concerning the most salient facts and features of the billfish stocks and fisheries in the Western Central Atlantic Fisheries Commission (WECAFC) region (Figure 1) of the Food and Agriculture Organization of the United Nations (FAO). Dr Nelson Ehrhardt and Dr Mark Fitchett of the Rosenstiel School of Marine and Atmospheric Science of the University of Miami in the United States under contract with the International Game Fish Association (IGFA) prepared this desk study. IGFA is a partner with FAO in the Caribbean Billfish Project (CBP) funded through the World Bank (WB). Results of Activity 2.1.2 of the project will serve as the information base to support development of a billfish fisheries management plan included as one of the main outputs in the CBP.

FIGURE 1

**Western Central Atlantic Commission (WECAFC) area within the International Commission for the Conservation of Atlantic Tunas (ICCAT) Convention area**



## 2. BILLFISH SPECIES OF INTEREST AND UNITS OF STOCK

### 2.1 Brief biological synopsis critical to the objectives of this review

#### *Systematics and classification*

Billfishes (marlins, sailfish and spearfishes) belong in the bony fish order Perciformes. However, classification of billfishes remains unsettled in terms of sub-order, genera, and species. In this review, we considered the traditional works of Nelson (1994 and 2006) and of Collette *et al.* (2006). The later authors utilized genetic and morphological data that may provide more definite conclusions on the billfish species classification.

According to Collette *et al.* (2006) billfishes are genetically and morphologically distinct enough from scombroids (tuna and tuna like species) to merit placement in a separate suborder, Xiphioidae, and two extant families are recognized within the suborder: Xiphiidae (swordfish, *Xiphias*) and Istiophoridae (Table 1). Individuals of the Istiophoridae family are characterized by a rounded bill, a lateral line retained throughout life, elongate pelvic fins, a dorsal fin with a very long base that is sometimes sail-like and is depressible into a groove, and a caudal peduncle in the adult with two keels on each side (Nelson, 2006). Other characteristics are scales present in the adult, jaws with teeth in the adult, and 24 vertebrae. The members of this family share several characteristics with the swordfish; including an elongate premaxillary bill (rostrum) in adults, dorsal fin origin over back of head, pectorals low on body, and first dorsal fin lacking true spines. Further morphological and meristic descriptions by species are found in the Chapter 2 of the International Commission for the Conservation of Atlantic Tunas (ICCAT) Manual (ICCAT.INT).

Family Istiophoridae is divided into five genera (Collette *et al.*, 2006; Integrated Taxonomic Information System, ITIS 2008), as follows: *Istiompax* (black marlin), *Istiophorus* (sailfish), *Kajikia* (white and striped marlins), *Makaira* (blue marlin), and *Tetrapturus* (spearfishes). The authors claim that there is no genetic evidence to support recognition of separate species of Atlantic and Indo-Pacific sailfishes or blue marlin, while Atlantic white marlin is closely related to Indo-Pacific striped marlin. There are four spearfish species and they are closely related: the two Atlantic species, longbill and roundscale, the Mediterranean spearfish, and the Indo-Pacific shortbill. In summary, the classification of billfishes following Collette *et al.* (2006) and ITIS (2008) is presented in Table 1.

Four billfish species are of concern in this desk study: Atlantic blue marlin (*Makaira nigricans*), white marlin (*Kajikia albida*), Atlantic sailfish (*Istiophorus platypterus*) and roundscale spearfish (*Tetrapturus georgii*).

Table 1

**Classification of Istiophorid species according to Collette *et al.* (2006)**

Phylum : Chordata	
└	Subphylum Vertebrata
└	Superclass Gnathostomata
└	Class Osteichthyes
└	Subclass Actinopterygii
└	Infraclass Teleostei
└	Superorder Acanthopterygii
└	Order Perciformes
└	Suborder Scombroidei
└	Family Scombridae <b>Tuna, bonito and mackerel species</b>
└	Suborder Xiphioidae
└	Family Istiophoridae <b>Billfish species</b>
└	Family Xiphiidae <b>Swordfish</b>
Family <i>Istiophoridae</i>	
•	Genus <i>Istiompax</i> (Whitley, 1931)
◦	<i>Istiompax indica</i> — <b>Black marlin (Pacific)</b>
•	Genus <i>Makaira</i> (Lacepède, 1802)
◦	<i>Makaira nigricans</i> — <b>Blue marlin (Pacific and Atlantic)</b>
•	Genus <i>Kajikia</i> (Hirasaka and Nakamura, 1947)
◦	<i>Kajikia albida</i> — <b>Atlantic white marlin</b>
◦	<i>Kajikia audax</i> — <b>Indo-Pacific striped marlin</b>
•	Genus <i>Istiophorus</i> (Shaw, 1792)
◦	<i>Istiophorus platypterus</i> — <b>Indo-Pacific sailfish</b>
•	Genus <i>Tetrapturus</i>
◦	<i>Tetrapturus pfluegeri</i> (Robins and de Sylva, 1963)— <b>Longbill spearfish</b>
◦	<i>Tetrapturus georgii</i> (Lowe, 1841)— <b>Roundscale spearfish</b>
◦	<i>Tetrapturus belone</i> (Rafinesque, 1810)— <b>Mediterranean spearfish</b>
◦	<i>Tetrapturus angustirostris</i> (Tanaka, 1915)— <b>Indo-Pacific shortbill</b>

**Growth**

Growth is relatively the simplest to estimate among all fish population parameters and it is the most important of the population parameters describing population dynamic characteristic of fish species. Life span as defined by knowledge of growth correlated with natural mortality, which together with growth is core to the interpretation of population sustenance. Knowledge of growth allows interpretations of age compositions; thus age compositions may be used to estimate natural and fishing mortality factors. Abundance at age allows interpretation of parental stock and the fate of recruitment, etc. Most of the advanced fish stock assessment methods rely on growth and on those parameters that are estimated from growth functions for successful convergence of stock assessment models to observed data such as catch and catch per unit of effort. In this summary on billfish growth, we make special reference to the species biological synopsis found in Chapter 2 of the Species Directory in the ICCAT Manual (i.e. Publications in ICCAT.INT). In that chapter, Arocha and Ortiz (2006a and 2006b) express that growth functions for blue marlin and sailfish do not exist for applications in ICCAT stock assessments. Similarly, Hoolihan (2013a) mentions that white marlin growth has been attempted using hard parts and tagging data but growth functions for the species are not reported or defined for stock assessments. Regarding roundscale spearfish, Hoolihan (2013b) expresses that age

determination and growth studies have not been undertaken and no growth model is available for the species.

Notwithstanding the critical need of growth to assess status of billfish exploitation, the literature reviewed on growth of Atlantic billfishes provides problematic and unsettled information on the parameters of billfish growth functions. Reference is made to the von Bertalanffy growth function parameters  $K$  (coefficient of growth),  $L_{\infty}$  (asymptotic length) and  $t_0$  (the arbitrary age at length zero). Die and Drew (2008) assessed the available growth data for white marlin and described annual periodicity in the annuli formation in anal fin spines and estimated parameters for von Bertalanffy growth functions for several age-size regression ranges. To avoid the effects of lack of data among younger ages (0 to 2 years), which creates a statistical artifact of estimating highly negative  $t_0$  concomitant with jointly under estimating  $K$ , the authors offer function parameters estimated when  $t_0$  was set to zero. Restricted  $t_0$ -parameter estimates for  $L_{\infty}$  are about 160 cm and 166 cm LJFL for males and females, respectively. These estimates correspond to the mode in the length frequency data collected in the fisheries during the last decade (Figure 7 in Annex 6 ICCAT SCRS/2012/012). The authors report that most data for growth covers ages 3 to 8; however, life span of white marlin estimated from time at large of tagged white marlin is over 15+ years (Ortiz *et al.*, 2003).

Figure 8 in the 2012 white marlin stock assessment (ICCAT SCRS/2012/012) shows that less than 3 percent of individuals above 200 cm LJFL are found in decadal landings during the 2000's while decadal landings during the 1970s included approximately 36 percent of individuals greater than 200 cm LJFL. Therefore, the asymptotic lengths in the growth functions of Die and Drew (2008) may not be representative of the white marlin population, but rather an artifact of low availability of larger sized samples due to enduring exploitation. On the other hand, Laretta and Brown (2012) estimated growth parameters for white marlin estimated from capture-recapture data. The resulting  $L_{\infty}$  is 218 cm LJFL. Such parameter passes through length frequencies of the largest individuals reported in Figure 7 of the size frequencies in landings of white marlin reported in Annex 6 of the 2012 white marlin stock assessment. The interpretation here is that the results reported by Die and Drew (2008) based on direct ageing may be affected by a narrow age-size regression range in samples characterizing a heavily exploited resource.

Age estimates have also been made on blue marlin (Wilson *et al.*, 1991; Prince *et al.*, 1984) but growth models have been restricted to juveniles (Prince *et al.*, 1991) mostly due to the difficulties of ageing older fish. Sailfish age determination and growth have been studied by means of spines (Jolley, 1977; Hedgepeth and Jolley, 1983), size frequency analysis (De Sylva, 1957), and tagging (Ehrhardt and Deleveaux, 2006). Depending on data sources and methodologies used, sailfish length-age functions are very different, implying some fundamental differences in the information provided by the data and the methods used to interpret the data. In Ehrhardt and Deleveaux (2006), a  $t_0$ -correction of the Hedgepeth and Jolley (1983) data is offered and comparisons of spine based growth functions and growth based on tagging provide a general agreement in that sailfish sexual dimorphism may be pronounced in the Atlantic species.

The aforementioned results illustrate the fact that billfish present unique issues regarding determination of growth. This is due to many factors including difficulties of securing objectively collected data for growth from wide-ranging and solitary behavior of billfish species that are mostly caught as bycatch in industrial fisheries. As such, billfish access under varying selectivities and availabilities mar the process of making collection of sufficient samples over adequate size-age regression ranges (Radtke and Shepherd, 1991). In addition to difficulties in securing proper spatial and temporal billfish samples, there are complex technical issues describing time scales of growth in billfish hard parts as well as size scales among individuals measured. Time scales of growth are obtained by aging billfish mostly from spine sections usually extracted from dorsal or pelvic fins, but also from otoliths or from tagging experiments. However, spine sections have the great inconvenience of vascularization at the center (focus) of the sections; thus preventing accurate determination of the first annual rings among older individuals.

Kopf *et al.* (2010) provide the first general comprehensive frame for standardizing techniques and analytical procedures to secure proper age validation from spine sections in striped marlin and white marlin. Such approach may also be applicable to other billfish species showing spine section vascularization. On the other hand, billfish otoliths are small and fragile, with complex and divergent axis of growth, and very difficult to extract from the cranium. These characteristics create logistic problems for collecting otoliths at sea by the free will of fishing crews or observers aboard. In general, it has been shown that using otoliths for direct estimation of age in billfishes are impractical, laborious, and expensive to collect, while they do not provide accurate age readings among older fish (Prince *et al.*, 1991).

Collection of hard parts from billfish landings is especially difficult because most fisheries that capture billfish often land dressed products (i.e. carcasses of headless and eviscerated billfish). Therefore, hard parts with identification of species, length and sex cannot always be obtained in biological sampling programs. Tagging studies planned for elucidating billfish growth are also not free of major statistical issues. For example, size changes while at large in tagging studies provides an amount of growth (i.e. the change in size from times at tag release to recapture) but billfish sexes cannot be determined at time of release. Therefore, unless sex is reported by those recovering tags from retained fish, it will never be known the effect of sexual dimorphism in billfish growth databases. Also size at release is oftentimes guess-estimated at best and size at recapture is usually not made by standardized means (i.e. ad hoc measurements done by non technical personnel that caught and retained the tagged fish). Therefore, securing proper size and sex description in tagging studies is challenging for billfishes. When sexual dimorphism is not incorporated in the measurements, it may render tagging data of very little use for growth studies. Ehrhardt and Deleveaux (2006) reviewed the tag-recapture data concerning sailfish in the Atlantic and noticed the conspicuous separation of two groups of data pertaining to growth rates plotted on size at release. Based on qualitative observations of dichotomy in growth rates, Ehrhardt and Deleveaux (2006) suggested that such partitioning might be due to sexual dimorphism in growth.

On the other hand, size scales to determine growth also are challenging in billfish growth studies in the sense that billfish species grow very quickly in length during their first 2 years of life and then they significantly change in body shape as they age. As a result, growth in length tends to be steep at earlier ages and then become suddenly quasi-asymptotic. Many studies on billfish growth are challenged by the nature of this growth characteristic and the appropriateness of the von Bertalanffy growth function to represent growth among billfish species has been questioned (Ehrhardt 1992; Chiang *et al.*, 2004). The main effect is the curvature of the growth function as expressed by the growth coefficient (K) of the von Bertalanffy growth function. The usual lack of juvenile billfish in samples of the reviewed growth works reflect the presence of highly negative estimates for the  $t_0$  parameter of the von Bertalanffy growth function. Since parameters are jointly estimated, highly negative values of  $t_0$  coincides with significantly underestimated K parameter estimations. As such, the few existing billfish growth functions appear to fit well the observed age range of fish in the landings but may grossly overestimate the size at earlier ages and underestimate the sizes of absent size frequencies from older, overexploited age classes. Therefore, billfish growth parameters in the reviewed works may not represent the character of growth of the species, but for certain ages and for certain exploitation levels. This difficulty represents a major shortcoming to stock assessment efforts that use age/size structured models.

This review observes that challenges of interpreting and validating billfish age estimates from different sources (i.e., hard parts, length frequencies and tagging) remain highly uncertain and while growth is insufficiently known; therefore, advanced stock assessment techniques will remain compromised when growth parameters with high levels of uncertainty are applied to billfish assessments.

## Natural mortality

The cryptic nature of natural mortality makes its estimation very difficult. This is critical because the level of natural mortality ( $M$ ) is paramount to the measure of stock productivity and in the calculation of biological reference points (e.g.  $MSY$ ,  $F_{0.1}$ ,  $F_{MSY}$ , etc.). Natural mortality has not been empirically estimated for Atlantic billfish species; however, assumptions have been made about  $M$  from simulation models and expert opinions. The adopted  $M$  in blue marlin has been 0.139 (Schirripa 2011) and 0.15 (Prager and Goodyear 2001) and for white marlin  $M = 0.10$  (Porch 2003) and  $M = 0.20$  (ICCAT 2012 Stock Assessment Annex 6). Mather *et al.* (1971) estimated a total mortality rate ( $Z$ ) for white marlin in the western Atlantic from tagging experiments carried out between 1954 and 1970. The resulting  $Z$ -estimate is 0.32 annually at a time when exploitation of the billfish resources had already started and more than 150 000 white marlin were landed in 1964 (Ueyanagi *et al.*, 1970, Figure 25). As such it may be assumed that  $Z$  must contain natural mortality as well as fishing mortality ( $F$ ); therefore,  $M$  should be less than 0.32 during those years.

Mark-recapture records suggest that white marlin are capable of living 15+ years (Orbesen *et al.*, 2008; Ortiz *et al.*, 2003). Adopting the empirical natural mortality formulation of Hewitt and Hoenig (2005) to estimate  $M$  from maximum age, result in that white marlin should have a natural mortality of 0.27 if life span is 15 years. The resulting  $M$  is reasonably matching the potential, yet unknown,  $M$ -value that should be contained in the  $Z$ -estimate of 0.32 given by Mather *et al.* (1971) for the early years of exploitation. Atlantic sailfish longevity is at least 17+ years based on the longest time at large of a tagged recaptured Atlantic sailfish (Ortiz *et al.*, 2003). Using the empirical formulation of Hewitt and Hoenig (2005) results in  $M = 0.24$ . Maximum age of Atlantic blue marlin estimated from time at large in tagging experiments is 11+ years (Ortiz *et al.*, 2003). This life span estimate is low relative to the maximum age of the same species in the Pacific that could reach 28+ years in females and 18+ years in males when estimated from otoliths (Hill *et al.*, 1989). Goodyear (cited as personal communication in the white marlin stock assessment report) suggested the use of a maximum age of 23 years for blue marlin resulting from averaging the maximum ages for males and females found in the Pacific, in which case  $M$  estimated using the Hewitt-Hoenig formulation should be 0.17.

It may be suggested that on average the three species in the Atlantic may have maximum ages between 15 and 20 years in which case  $M$  should range between 0.27 and 0.20, respectively. This  $M$ -range agrees in the lower limit with the  $M$  value adopted from white marlin, but in general is significantly larger for some of the other species in the billfish stock assessments reviewed.

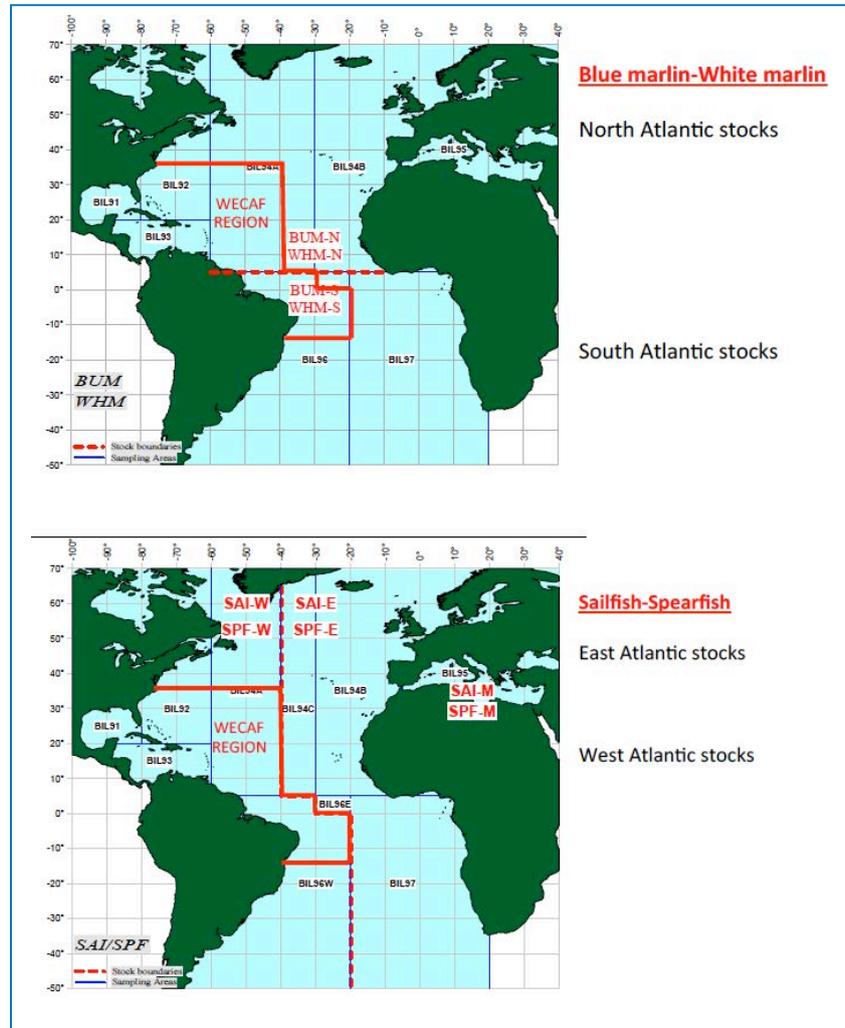
## Abundance distribution, reproductive dynamics, and units of stock definitions

Unit of stock definitions for marine organisms are of fundamental importance for the purpose of management and the implementation of conservation measures. It also is used to frame fishery statistical systems and to carry out stock assessments. To define units of stock, several methods are available and usually a combination of methods are used to define spatial temporal limits to stock composition and habitat domain. Logistic, economic and social considerations are also included in such definitions. Genetic and tagging studies are most suitable to mark differences among areas and habitats used by the species of concern, but also surveys of different sorts (e.g. larval and fishery) are used to demarcate persistent temporal spatial distributions that may define feeding and reproductive dynamics of the species. ICCAT has defined general areas of the Atlantic Ocean to demarcate managerial billfish units of stocks. There is a north and south Atlantic stock division for marlins and an east and west demarcation for sailfish and spearfish (Figure 2). The WECAFC region comprises fractions of these areas (Figure 2) potentially creating discrepancies regarding the ICCAT definition of billfish stock units. In general, the extension of the units of stock defines the sampling domain for objectively collecting fisheries data for stock assessment purposes as well as management.

In this desk study we include the earliest available findings regarding potential billfish stock distributions in the Atlantic Ocean. For this purpose, spatial Japanese billfish relative abundance surveys carried out in the Atlantic Ocean between 1956 and 1966 (Ueyanagi *et al.*, 1970) and

comprehensive worldwide larval surveys reported by Nishikawa, *et al.* (1985), which include the Atlantic Ocean, are considered.

**FIGURE 2**  
**Boundaries for billfish stock definitions in the ICCAT Convention area showing (in red) the WECAFC boundary region**

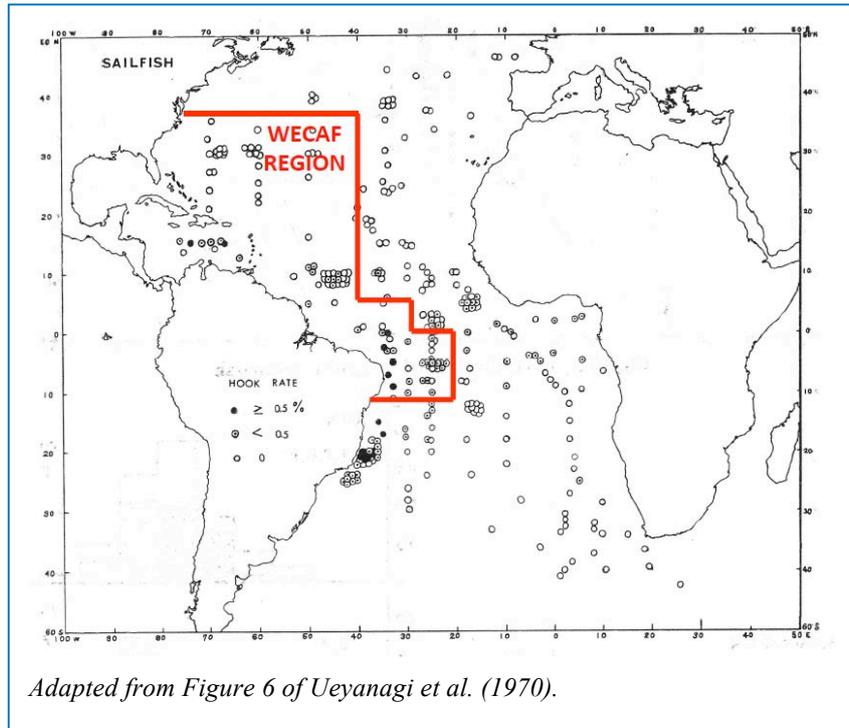


According to Ueyanagi *et al.* (1970), sailfish were most densely distributed in waters closer to land masses in the tropical and subtropical areas of the Atlantic Ocean (Figure 3; Adapted from Figure 6 in Ueyanagi *et al.*, 1970). The authors mention that spawning activity is likely higher in the eastern and western sides of the Ocean. Nishikawa *et al.* (1985) mention that in the Atlantic Ocean, sailfish larvae occurred in three main areas: the Gulf of Guinea, the Caribbean Sea, and off the east coast of Brazil, which coincides with the general conclusions about sailfish spawning found in Ueyanagi *et al.* (1970). In the WECAFC region, billfish reproductive studies show limited spatial coverage and reduced time scales that limit their value regarding relative time and distribution of spawning areas for the units of stock. Sailfish observations found that larvae and ripe female sailfish with varying spawning schedules that may vary from year-round to a spawning season from May to September in the Florida Current (De Sylva and Breder 1997; Post *et al.*, 1997; Luthy *et al.*, 2005; Richardson, 2009 a and b; Richardson *et al.*, 2010). The later results coincide with sailfish spawning seasons obtained by Simms *et al.* (2010) with samples from the northern Gulf of Mexico. In the southeastern Caribbean Sea, Arocha and Marcano (2006) report sailfish spawning from June to December, while spawning schedule in the western central Atlantic between 13°N and 5°N is from February to September. Schmidt *et al.* (2015) reports the presence of sailfish larvae in the southwestern Atlantic (20°S, 39°W), over the continental shelf along southern Brazil in January. This finding supports earlier work by

Hazin *et al.* (1994) and Mourato *et al.* (2009) regarding sailfish spawning during the period December to March in the southwestern Atlantic off Brazil as well as the reported sailfish spawning area and season found previously in Nishikawa *et al.* (1985) in the same region.

FIGURE 3

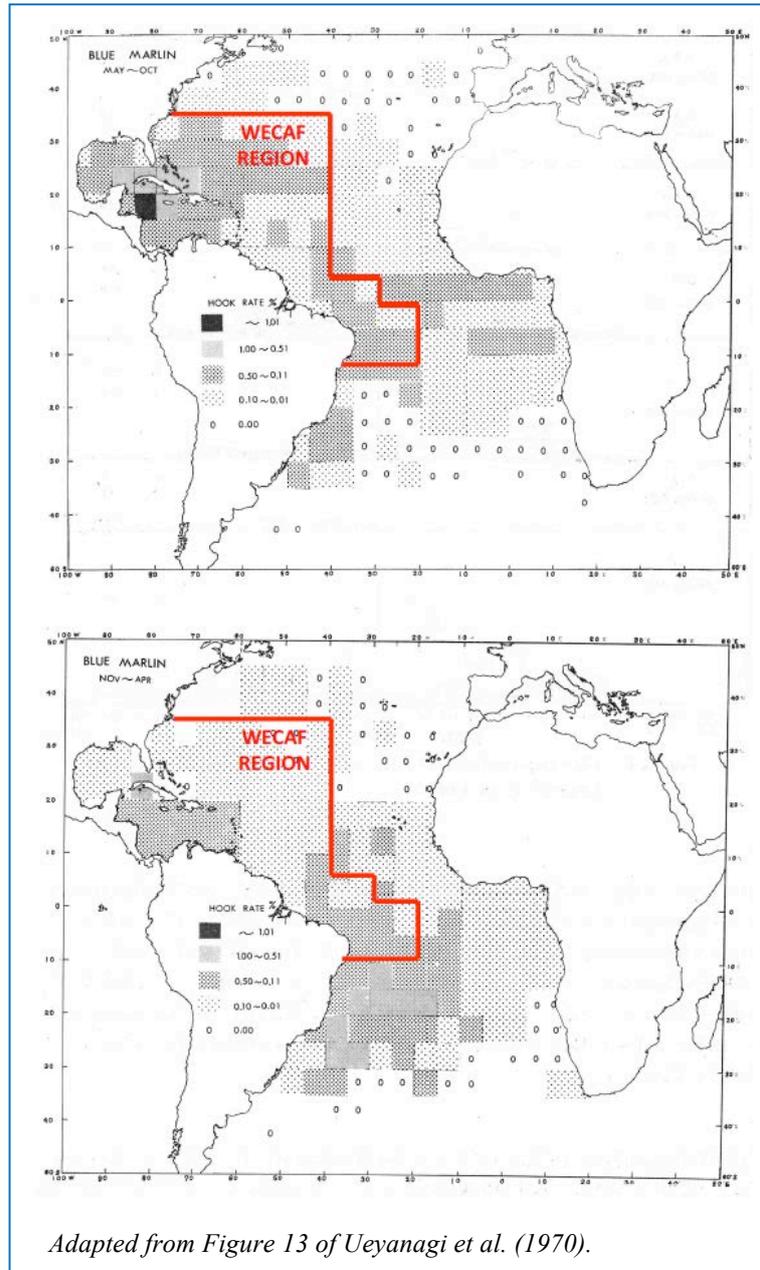
Original sailfish relative abundance distributions in the Atlantic Ocean



Regarding blue marlin, Ueyanagi *et al.* (1970) mention that the species was found sparsely distributed throughout the eastern parts of the Atlantic Ocean but showing two high seasonal concentrations, one in the northwestern Atlantic in the northern summer and the other in the southwestern Atlantic in the southern summer (Figure 4; adapted from Figure 13 in Ueyanagi *et al.*, 1970). They also mention that spawning fish appear to be the major constituents of those concentrations. Nishikawa *et al.* (1985) observe that larvae of Atlantic blue marlin, mainly occurred in the South Atlantic Ocean off the east coast of Brazil between 9°S and 25°S latitudes with an insignificant number of larvae collected north of the equator. However, more recent studies in the North Atlantic, spawning of blue marlin females and larvae have been found in waters of the Straits of Florida along the southeastern United States (Richardson 2009b; Luthy *et al.*, 2005), Puerto Rico and the Virgin Islands (Erdman, 1968), The Bahamas (Serafy *et al.*, 2003), Dominican Republic (Prince *et al.*, 2005), Jamaica (Caldwell, 1962), and Bermuda (Luckhurst *et al.*, 2006). In the southeastern Caribbean Sea and in the western central Atlantic between 13°N and 5°N, spawning females with hydrated oocytes in their gonads have been recorded during June–August off the Venezuelan coast and off the coasts of Guyana and Suriname (Arocha and Marcano, 2006). In the equatorial Atlantic (5°N–5°S), spawning takes place in the waters of northeastern Brazil (Travassos *et al.*, 2006). In the South Atlantic, blue marlin spawning recorded from reproductively active gravid females and larvae collections occur off the southern Brazilian coast between 10–30°S (Amorim *et al.*, 1998). From information provided in the previous references, blue marlin spawning occurs mostly from May to October in the North Atlantic, while in the equatorial Atlantic (7°N–20°S), spawning seems to occur during June–August. Observations in the Southwest Atlantic indicate that reproduction events take place from November to April. Spawning seasons reported in the scientific literature seems to confirm the findings of Ueyanagi *et al.* (1970) which stated that seasonal distributions of the blue marlin relative abundance appear to correspond to spawning stocks, one in the northwest Atlantic and another in the southwest Atlantic.

FIGURE 4

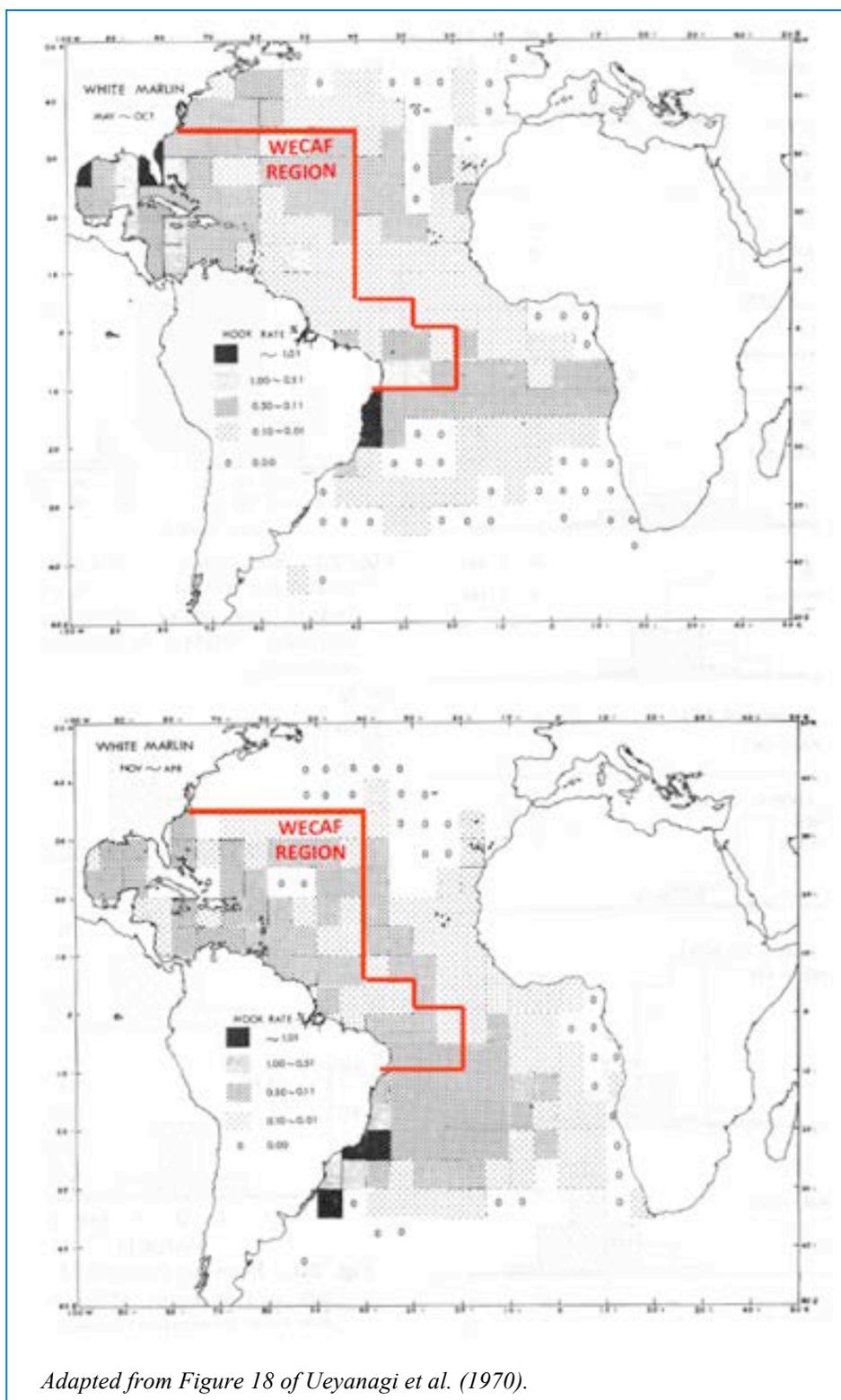
## Original blue marlin relative abundance distributions in the Atlantic Ocean



Ueyanagi *et al.* (1970) refer that white marlin are most abundant in subtropical and temperate waters of the North and South Atlantic Ocean and relatively scarce in the intermediate tropical waters (Figure 5 adapted from Figure 18 in Ueyanagi *et al.*, 1970). They also mention that white marlin appear to migrate to temperate waters to feed and to subtropical waters to spawn. In the figure there are clear evidence of separate abundance of white marlin in the northwestern and southwestern Atlantic. Nishikawa *et al.* (1985) report that white marlin larvae were found along the east coast of Brazil and in off-shore areas of Brazil. However, in the North Atlantic, they found very few white marlin larvae- mostly in the equatorial area at about 9°N latitude. The lack of white and blue marlin larvae in the Atlantic Japanese larval surveys north of the equator may be due to the less comprehensive area coverage of the survey in that region.

FIGURE 5

## Original white marlin relative abundance distributions in the Atlantic Ocean



More recent studies in the North Atlantic inform that white marlin spawning activity has been observed off eastern Florida USA (De Sylva 1963, De Sylva and Breder 1997, Luthy *et al.*, 2005), the Windward Passage and north of Puerto Rico (Baglin, 1979), northeast of Hispaniola and Puerto Rico (Arocha and Bárríos, 2009; Arocha and Marcano, 2006), and off the east coast of Hispaniola (Prince *et al.*, 2005). Spawning has also been reported for the equatorial Atlantic (5°N–5°S) off northeastern

Brazil (Oliveira *et al.*, 2007), and in the South Atlantic off southern Brazil (Arfelli *et al.*, 1986; Ueyanagi *et al.*, 1970). Information contained in the above references indicate that white marlin in the north Atlantic spawn from April to July, with peak spawning activity during April–May. In the equatorial Atlantic (5°N to 5°S), spawning occurs during May–June; and in the South Atlantic, reproduction events take place from December to March.

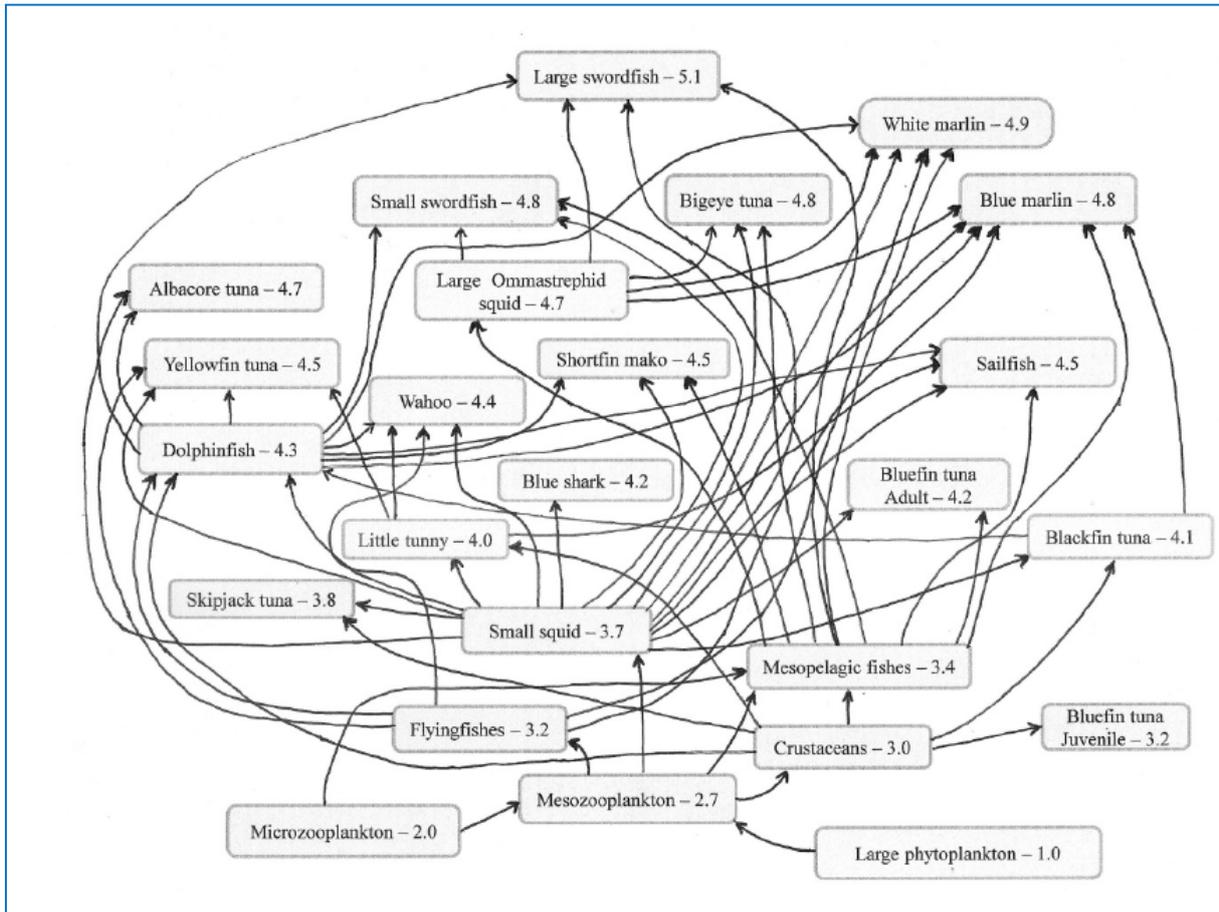
From the existing information on seasonal spatial abundance, localized studies on the larval seasonal distribution, and presence of mature females, it appears that the central, eastern and northern Caribbean Sea, northern Bahamas and northeastern Brazil regions are primary spawning areas for blue marlin, white marlin and sailfish in the western North Atlantic. As such, unit of spawning stocks are of prime importance in the WECAFC region. The implication of these findings is that regulations to control fishing on the spawning fractions of billfish populations will be essential to the long-range sustainability of billfish species in this region. At the same time, collections of appropriate data for stock assessment and management should be of fundamental interest to the WECAFC as a contribution to improving the existing ICCAT database.

## 2.2 Ecosystem interactions

Billfishes serve important functions in the marine ecosystem. Ecologically, they play an important role balancing marine food chains as apex predators. Kitchell *et al.* (2006) contend that billfishes are keystone predators in their respective ecosystems and have profound impacts on their food web, yet serve as indicators of fishery exploitation since fisheries have declined the abundance of billfishes as bycatch, more than that of targeted tunas. Ward and Myers (2005) attribute changes in abundance and catch composition in pelagic fisheries due to lower abundances of billfishes over time. In the western Atlantic, billfish primarily feed on squids and octopuses but also on small and medium size pelagic and mesopelagic fishes, tuna, tuna-like species, dolphinfish, and flying fish. Luckhurst (2015) developed a food web and energy transfer flow diagram for a Sargasso Sea pelagic ecosystem of importance to ICCAT (Figure 6). White marlin scores a high trophic score (4.9) in such food web consuming dolphinfish, large Ommastrephid squids, small squids, flying fishes, and mesopelagic fishes. It is followed by blue marlin (4.8), which consume large Ommastrephid squids, small squids, dolphinfish, flying fishes, mesopelagic fishes and black tuna. Sailfish is the lowest (4.5) among the billfish species in such food web consuming dolphinfish, little tuna, small squids and mesopelagic fishes. The food web for Istiophorid billfishes in the Atlantic is similar in structure and levels in the food chain (i.e. trophic scores of 4.5–4.9) as one developed by Olson *et al.* (2014) for the large pelagic ecosystem in the eastern Pacific Ocean (i.e. 4.5). In fact large piscivores in the Pacific model include billfishes and yellowfin tuna feeding on small piscivores including juvenile tunas, epipelagic forage fishes including flying fishes and cephalopods.

Of importance to the sustainability of billfish populations is the need to keep abundance of prey species at levels commensurate with bioenergetic demands of the top predators. In the case of the Atlantic billfishes it may be of considerable concern the fact that fish attracting devices (FAD) play an ecological role concentrating juvenile tunas that attract billfish as predators. Therefore, FADs increase catchability of the larger predators and their prey making them more vulnerable to exploitation. In fact, studies carried out on moored FADs in the WECAFC region (Guadeloupe, Dominica and Martinique) by French scientists (e.g. Doray 2004) demonstrate the formation of temporal food webs associated with the FADs (Figure 7).

FIGURE 6  
Food web of pelagic environment of the Sargasso Sea (Luckhurst, 2015)



Billfish species are mostly distributed in habitat-compressed areas of the World oceans. Ehrhardt and Fitchett (2006) demonstrated that billfish species in the eastern Pacific Ocean off Central America carry out localized regional migrations searching for prey species that are subjected to significant habitat compression and that are integrated in food webs such as the one presented by Olson *et al.* (2014). Habitat compression is well-known to tuna fisheries for a very long time. In fact, tuna purse seine fisheries have their origins in the eastern tropical Pacific in the late 1940's followed by such fisheries in the Gulf of Guinea and then the Indian Ocean. Habitat compression mechanisms derive from upwelling of low Dissolved Oxygen ( $DO_2$ ) waters as a product of biomass decomposition and biophysical factors (Prince and Goodyear 2006; Ehrhardt and Fitchett 2006; Prince *et al.*, 2010). Such habitat compression mechanisms favor an effective and efficient energy transfer in the large pelagic ecosystems and it is the base of a very productive and complex ecosystem in the eastern Pacific Ocean. Similar processes, but to a lesser scale, are observed in the Atlantic Ocean. Figure 8 shows the main areas in the Atlantic Ocean where billfish landings originated during the period 2000–2012. Most of the catches are associated to areas of the ocean where low  $DO_2$  levels of 1 mL/l depths are shallow (Clearer areas), thus facilitating aggregation of prey and their predators.

FIGURE 7

Diurnal fish aggregations, plankton/micronecton layers and fishing activity around moored FADs in Martinique (from Doray 2004, Figure 3)

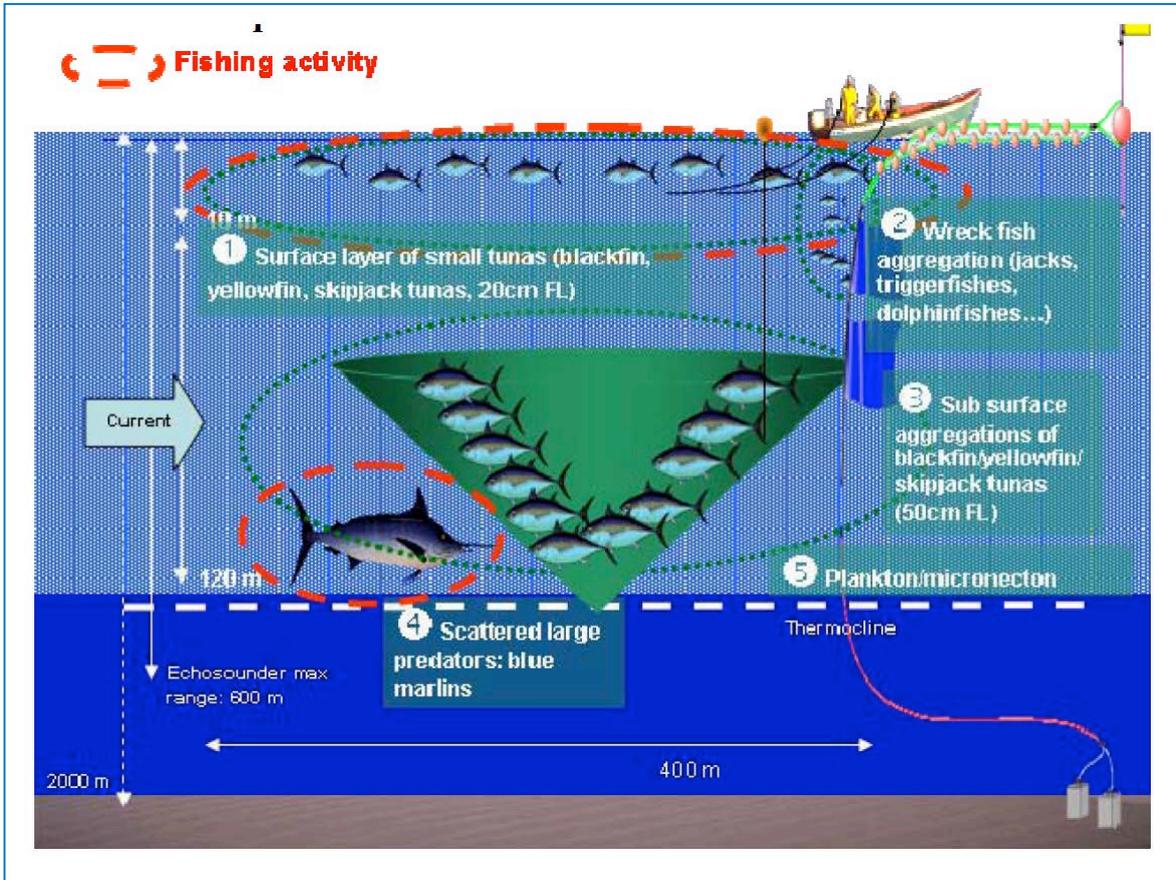
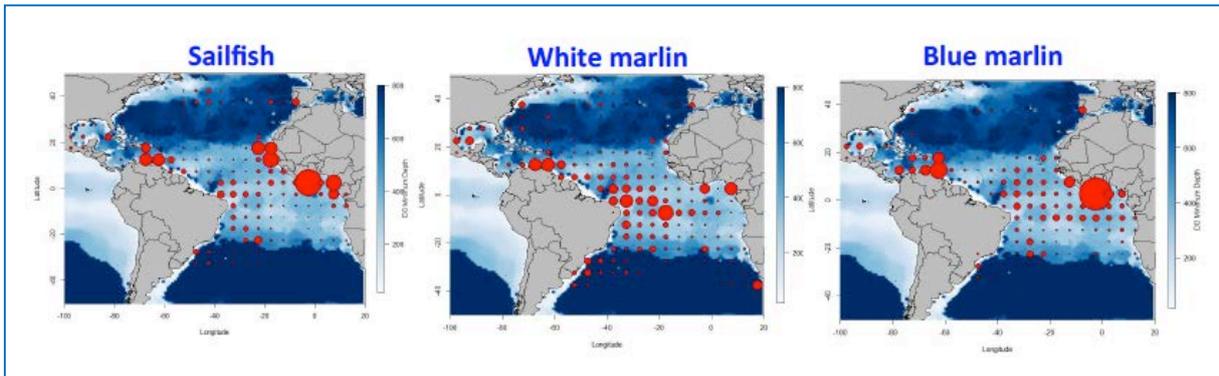


FIGURE 8

Maps with depths of the 1 mL/L dissolved Oxygen level in the Atlantic and eastern Pacific Oceans with over positions of most conspicuous areas where sailfish, white marlin and blue marlin were caught in the Atlantic Ocean during 2000–2012 (DO<sub>2</sub> at depth maps by the authors using data through the World Ocean Atlas and Task 2 catch statistics from ICCAT)

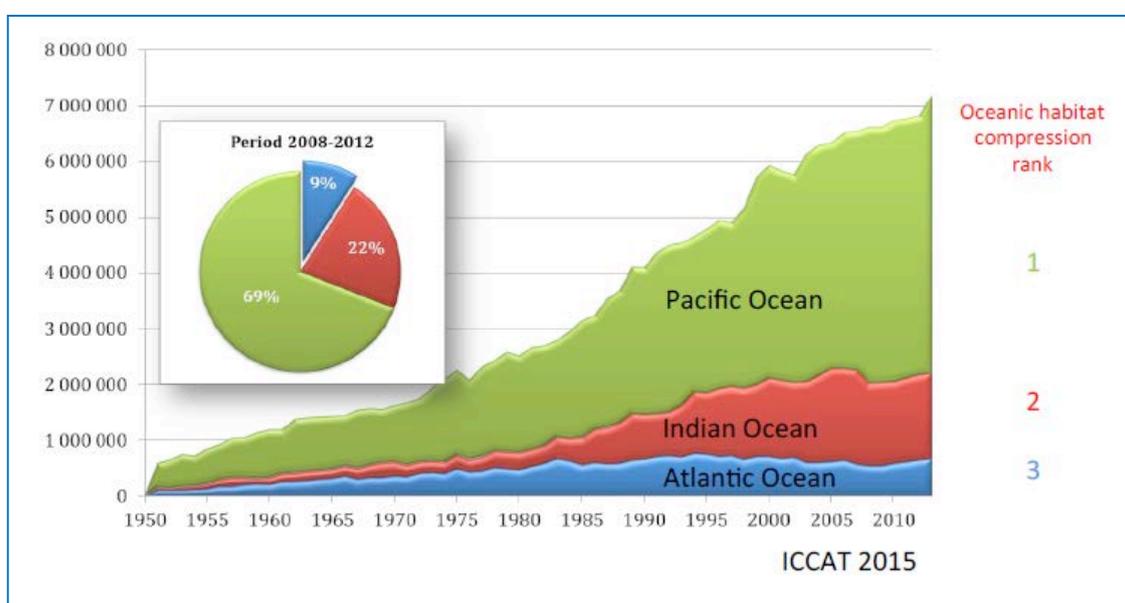


### 3. OVERVIEW OF THE BILLFISH FISHERIES IN THE WESTERN CENTRAL ATLANTIC

#### 3.1 Statistics and the fisheries

Billfish species are mostly caught as by-catch in tuna fisheries and to a much lesser scale, in directed highly localized coastal artisanal fisheries. The species are particularly popular in high-end sport/recreational fisheries in certain tropical areas where they are highly sought for its rarity, size, and excitement- including jumping out of the water as they are caught. A multi-million dollar recreational fishing industry has evolved worldwide based on billfish resources. Most modern sportfishermen release billfish after unhooking. The total landings of tuna, small tunas, and billfish by oceans reached slightly over 7 million tonnes in 2012 (Figure 9). There appears to be a correspondence among the ranked ocean habitat compression and the production of these large pelagic species in the different oceans. Landings of large pelagic species in the Atlantic reached only 9 percent of the total tuna, tuna-like species, and billfish species recorded worldwide in 2012. A slight decreasing trend in landings after 1995 is observed in the Atlantic Ocean (Figure 9).

FIGURE 9  
Landings in tonnes of tunas, small tunas, and billfish

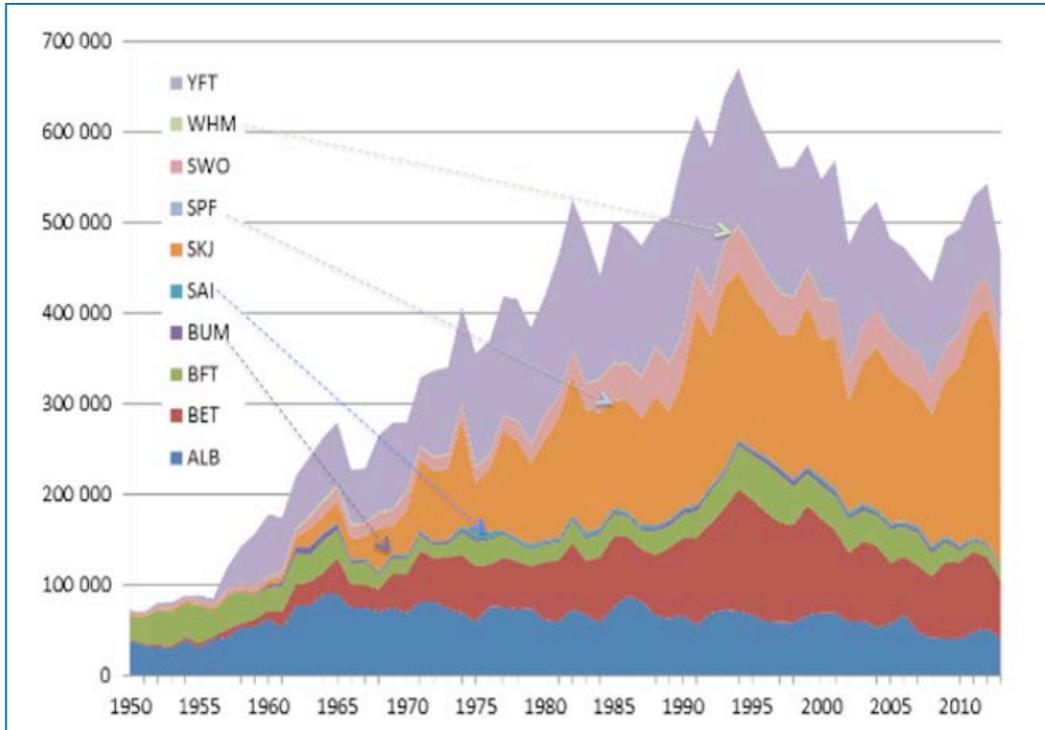


In the Atlantic, billfish landings represent 0.76 percent of the combined tunas, swordfish and billfish species (Figure 10). Sailfish and white marlin are almost undetectable in the statistics and blue marlin appears as the main billfish species reported in those statistics. The fact that billfish species comprise a very low percentage as by-catch in the landings of major tuna fisheries represents a significant impediment to objectively collect billfish stock assessment data through formal fishery statistical systems. This represents a challenge to integration of billfish stock assessment data. ICCAT is responsible for the research and management of tunas and billfish in the Atlantic Ocean. Assessments of billfishes (which will be discussed in following sections) are carried out periodically by scientists that wilfully contribute from member nations within ICCAT.

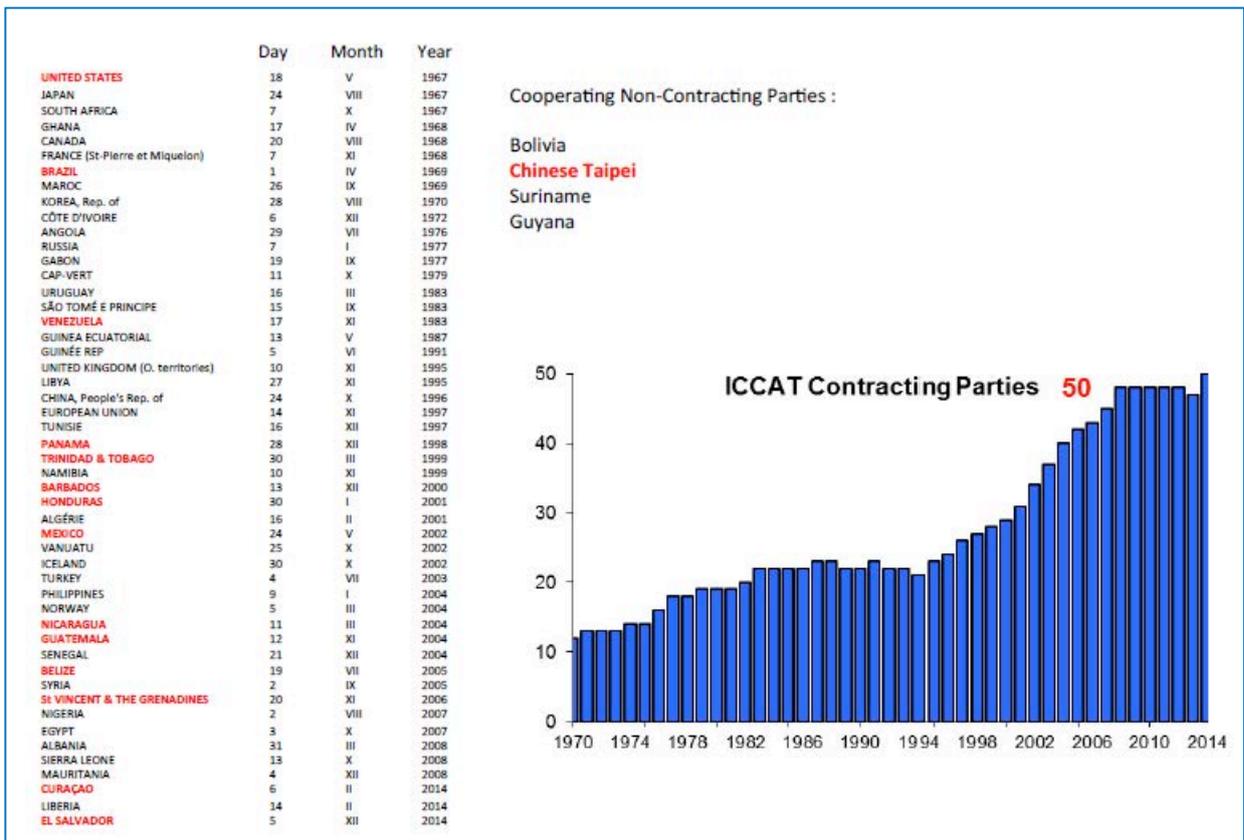
As of 2015 ICCAT has 50 contracting members countries, 14 of which are members of the WECAFC, and 4 Cooperating Non-Contracting Parties (Figure 11). ICCAT is depository of fishery statistics and biological research carried out by contracting and non-contracting countries. Fishery statistics are often reported as total estimates by year, fishery, and flag ('Task 1') and may be spatially explicitly reported by area (most commonly referred to as 'Task 2'). ICCAT analyses and integrates all information necessary to carry out stock assessments of the status of exploitation of the stocks and

generates annual quotas and regulations pertaining the sustainable use of the tuna and tuna-like resources in the area of the Convention.

**FIGURE 10**  
**Landings in tonnes of major tuna species, billfishes and swordfish**  
**from the ICCAT convention area (ICCAT 2015)**



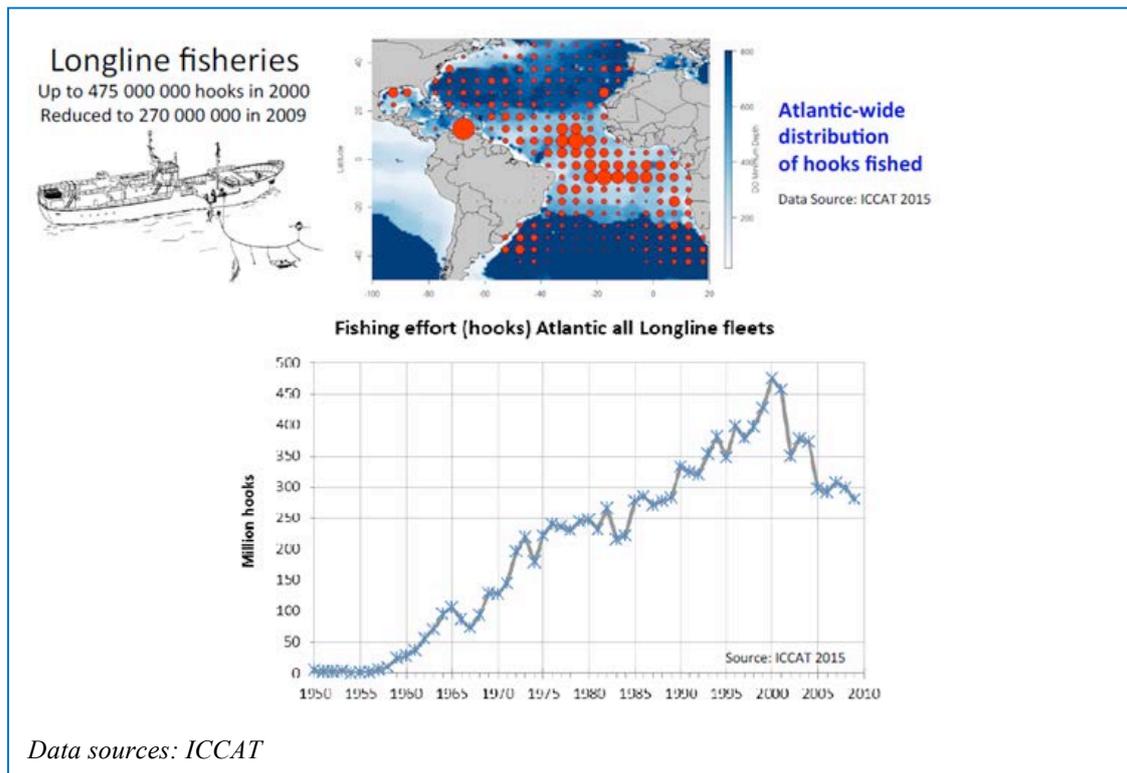
**FIGURE 11**  
**ICCAT contracting and cooperating non-contracting countries in 2015**



The industrial long line fisheries for Atlantic tuna resources prominently operate over the central equatorial Atlantic, as well as in the eastern Caribbean Sea (Figure 12), followed by areas in the northern Gulf of Mexico, the southwest Atlantic off the southern Brazilian and Uruguayan coasts, and off equatorial Africa. Longline fishing effort increased steadily from the 1950s until 2000, when over 475 million hooks were operated by all fleets fishing in the Atlantic (Figure 12). However, there has been a noticeable decrease in the amount of longline effort in the Atlantic due to removal of effort from some of the largest longline fishing countries (e.g. Chinese Taipei).

FIGURE 12

**Longline gear operational characteristics (upper left), spatial distribution of overall longline fishing effort in the Atlantic (upper right) and historic trend of longline fishing effort in the Atlantic in millions of hooks (Lower panel)**



The tuna purse seine fisheries in the Atlantic operate conspicuously in areas of the Gulf of Guinea where habitat compression is significant (Figure 8). Purse seine nets may be as deep as 250–300 meters – a depth sufficiently enough to reach depths within  $DO_2$  levels below 1 mL/L at which level fish cannot survive (Figure 13). Since the 1980s, a significant development that revolutionized tuna purse seining consisted in the introduction of sophisticated drifting Fish Aggregating Devices (dFAD). Since then large numbers of dFAD are deployed every year (Maufroy *et al.*, 2015) (Figure 13). In 2013, over 21 000 FADs were in use in the eastern Atlantic Gaertner *et al.* (2015). Bycatch associated to FAD and free-swimming schools (FSC) is given by Dagorn *et al.* (2012) and shown in the table below. The statistics show that FAD usage generates a very large discard of other tunas as well as undersized target tunas, while billfishes comprised 2.6 tonnes per 1 000 tonnes of tuna in FAD fishing as opposed to 5.1 tonnes per 1 000 tonnes of tuna retained (Table 2).

Table 2

**Species composition of bycatch and discards in FAD types**

Species	Atlantic	
	2003–2007	
	FSC	FAD
Target tunas <sup>1</sup>	0.0	61.0
Other tunas	20.8	67.7
Bony fish	0.8	17.0
Billfish	5.1	2.6
Sharks	0.3	1.8
Rays	1.4	0.2
By-catch total (without target tunas)	28.4	89.3
Ratio FAD/FSC		3.1

12.9% Juvenile Tuna discarded  
Tons per 1000 tons of targeted tunas

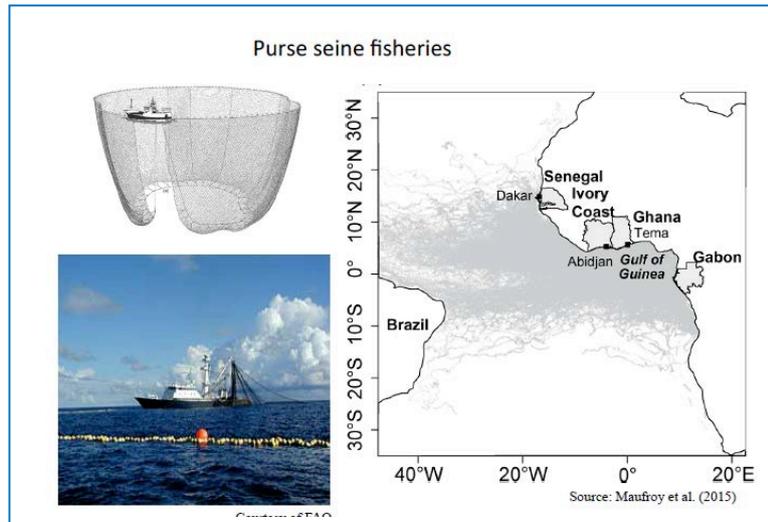
<sup>1</sup>Discards of target tunas. From: Dagorn et al. 2012

There is an extensive literature on the ecological, fishing efficiency and environmental impacts created by these dFADs with results that can be summarized briefly in the following seven critical points: 1) smaller size tunas are recruited to the dFADs, which are less valuable to the fishery and are significantly discarded, 2) increased bycatch that is mostly wasted, 3) dFADs drift away from tuna fishing grounds shortening the useable life of dFADs (approximately 35–50 days) requiring high replacement rates of about 9 000 dFADs per year (Baske *et al.*, 2012), which creates issues of non-operational derelict dFADs left free drifting in the ocean (Figure 14), 4) Coastal environmental impacts are expected but not yet evaluated given the washing ashore of non-operational dFADs (Figures 15 and 16), 5) FADs create navigational hazards that have not been quantified, 6) Massive dFAD densities are thought to impact in a yet unknown way the population dynamics of fishes in the large pelagic marine ecosystem. This is what has been termed as ‘ecological traps’ (Hallier and Gaertner, 2008), and 7) Changes in fishing efficiency and selectivity of tuna purse seiners fishing with dFAD impacted the use of CPUE indices needed for stock assessments. This is as a result of hyperstability of CPUE when this relative index of abundance does not decrease because technically dFADs keep attracting fish even when population abundances are decreasing due to population exploitation.

Presently, there are 107 large purse seine vessels operating in the Atlantic with a hold carrying capacity of 100 000 tonnes. In recent years this fleet carried out between 4 000 and 6 000 successful dFAD associated sets and about 2 000 successful non-dFAD associated sets. These fishing activities are concentrated in the eastern Atlantic (Figure 14) and may not have a direct impact on the fisheries in the WECAFC region. However, billfish by-catch, although minimal, it adds to the already highly depleted marlin stocks in the North Atlantic.

FIGURE 13

### Atlantic purse seiners and areas of the tropical Atlantic marked by drifting FAD tracks



Tuna and billfish are also targeted by gillnet fleets in Venezuela, Ghana, and in the southwest Atlantic. Venezuelan gillnetters operate in the eastern Caribbean Sea as well as offshore of the Guyana-Suriname region (Figure 17 upper left figure). Gillnetters mostly land blue marlin and longliners mostly land white marlin and sailfish (Figure 17 right figures).

Landings of Atlantic blue marlin fluctuated between 3 000 and 4 000 tonnes during the 2000s and most of those landings originated from longline operations and gillnetting. There is a conspicuous and persistent decrease in landings in the southwest Atlantic since the mid 1990s while in the north Atlantic landings decreased by at least 50 percent after 2000 (Figure 18). White marlin shows a significant decrease in landings both in the north and south Atlantic since the mid 1990s reaching less than 300 tonnes by the end of the 2000s. White marlin is almost exclusively landed from longline fishing operations (Figure 19). Sailfish in the east Atlantic declined to 1 100 tonnes in 2011 from a peak of 2 500 tonnes in 2007. In the western Atlantic, there is a significant decline from 1 700 tonnes in 2001 to less than 300 tonnes in 2013 (Figure 20). Eastern Atlantic sailfish landings were originated from longline and other surface gear in roughly equal proportions, while sailfish landings in the western Atlantic were mostly originated from longlining. Landings from sport fisheries in the western Atlantic were reduced to insignificant amounts after establishment of the catch-and-release regulation in the important US recreational fisheries (Figure 20).

Billfish landings by country in 2013 (ICCAT Fishery Statistics 2015) are given in Figures 21 through 23 where landings by countries in the WECAFC region are very conspicuous. In Figure 24, total historic landings of blue marlin, white marlin and sailfish for the period 2000–2012 are portrayed. There is a generalized decreasing trend in those landings with white marlin exhibiting the largest decline of about 50 percent followed by sailfish with about 45 percent.

FIGURE 14

Distribution of dFADs in the Indian and Atlantic Oceans (Panel a) and areas where purse seiners effectively use the dFADs marked by black dots (Panel b)

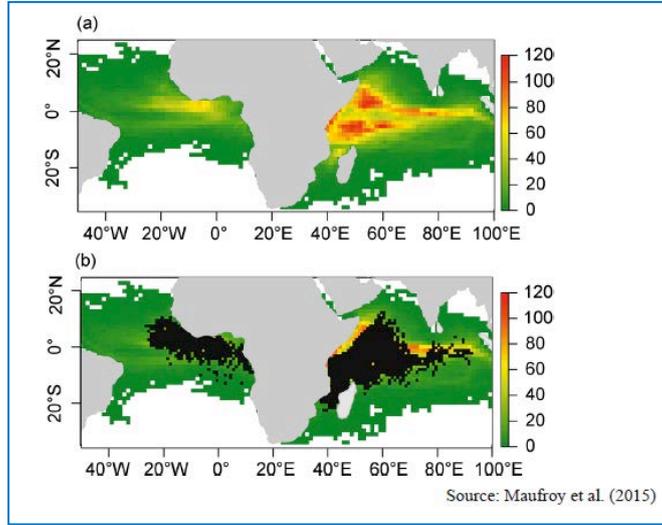


FIGURE 15

Beached dFAD (black dots) along the coasts in Brazil as well as in the Gulf of Guinea and in the Indian Ocean coastlines

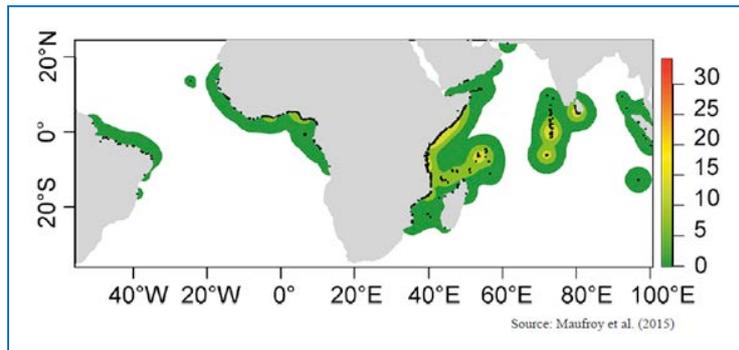


FIGURE 16

dFAD of Atlantic origin reported washed ashore on the Florida East coast



Source: Tom Matthews sent via GCFINET@LISTSERV.GCFL.ORG

FIGURE 17

Area of operation and landings of Venezuelan gillnet and longline fleets

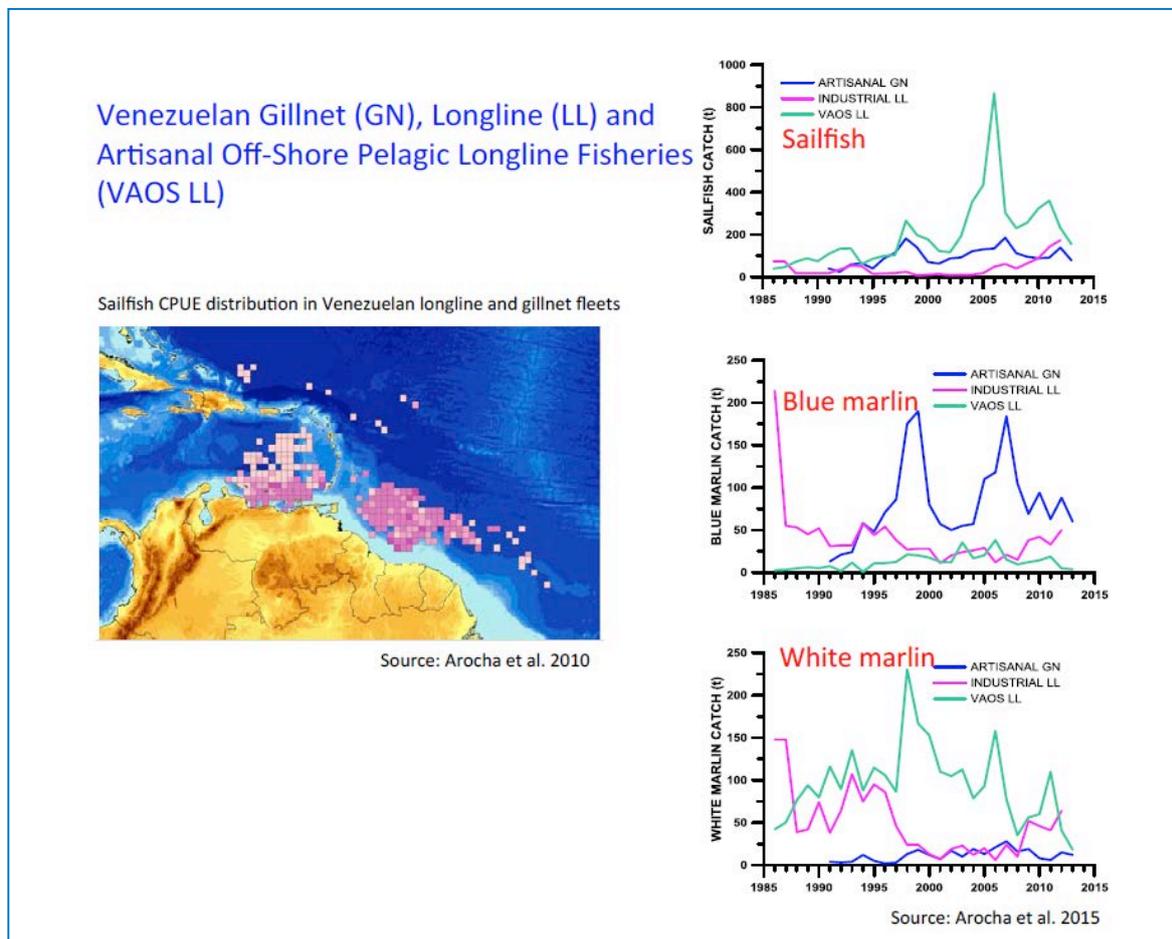


FIGURE 18

Historic blue marlin landings in the Atlantic Ocean (top figure) and landings by gear type in the north Atlantic (middle figure) and south Atlantic (bottom figure)

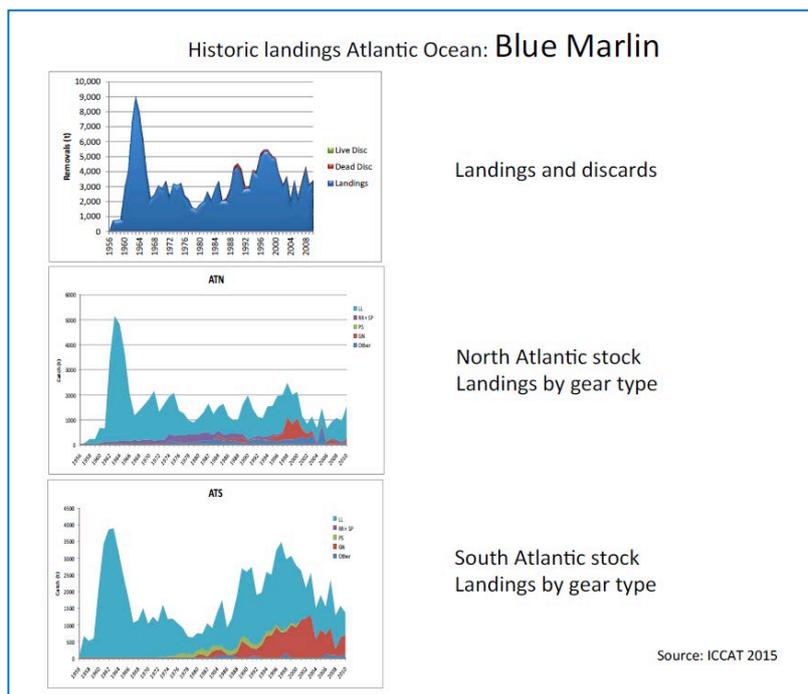


FIGURE 19

Historic white marlin landings in the Atlantic Ocean (top figure) and landings by gear type in the north Atlantic (middle figure) and south Atlantic (bottom figure)

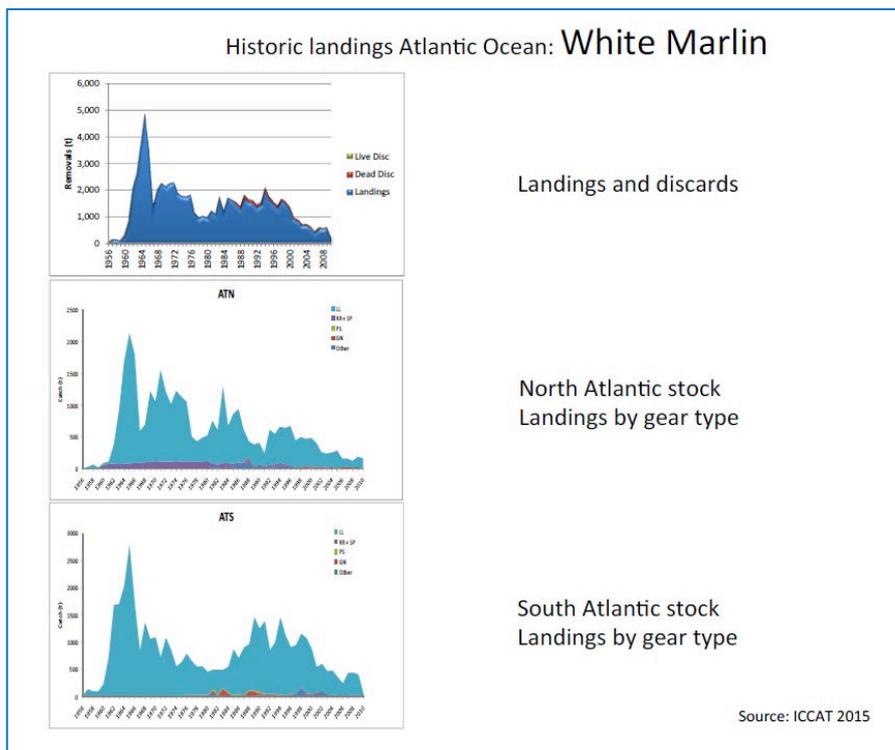


FIGURE 20

Historic sailfish landings by gear in the east Atlantic Ocean (top figure) and west Atlantic Ocean (bottom figure)

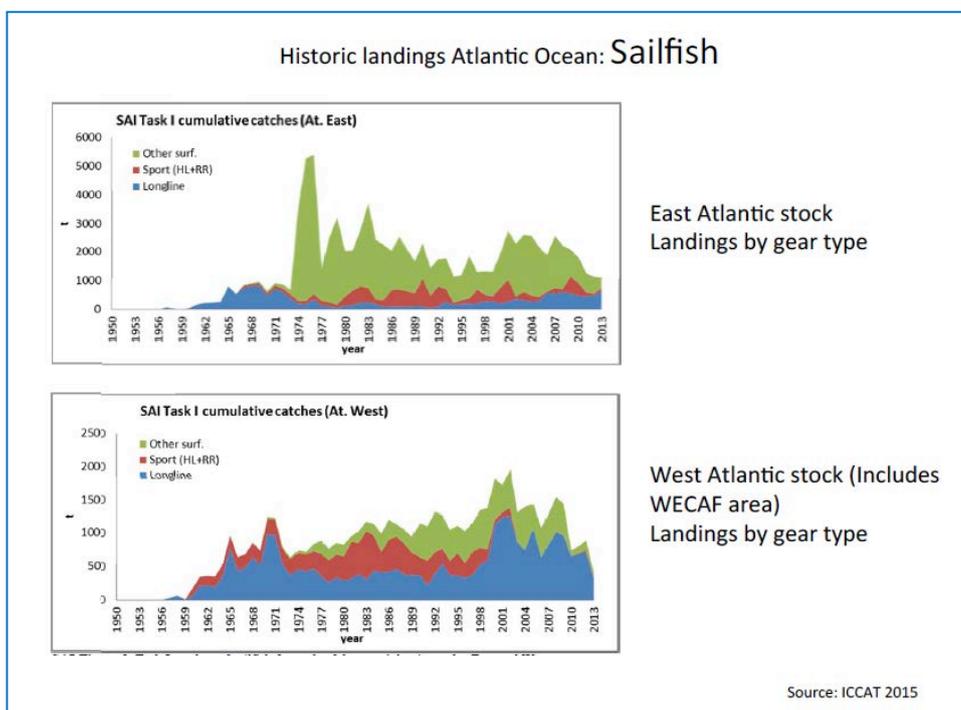


FIGURE 21  
Blue marlin landed by country within WECAF region

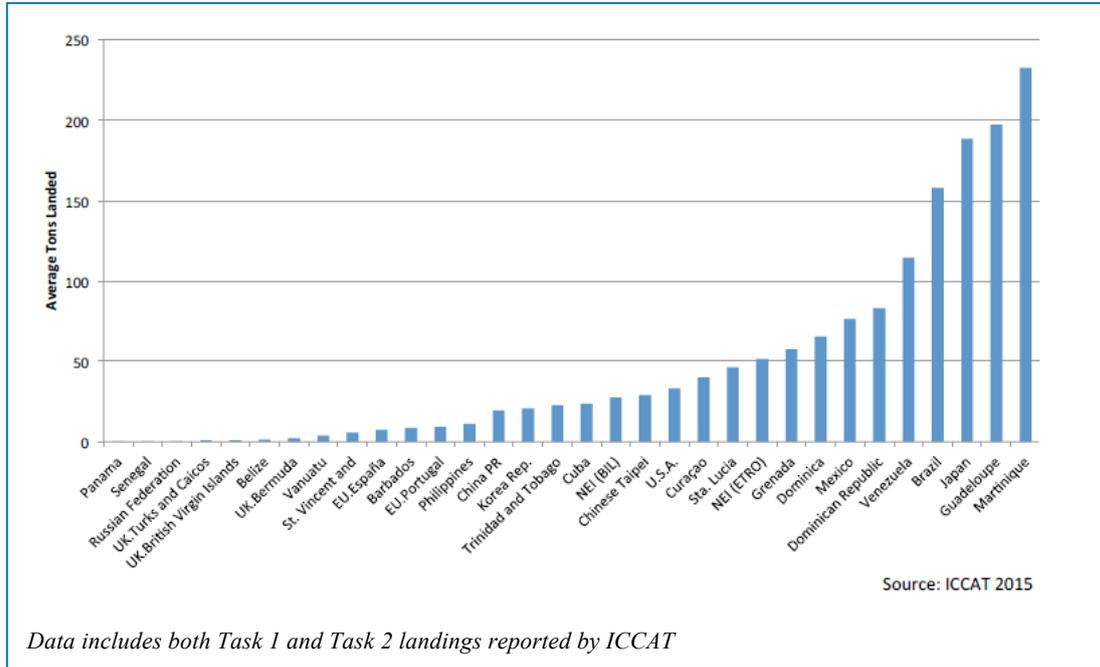


FIGURE 22  
White marlin landed by country within WECAF region

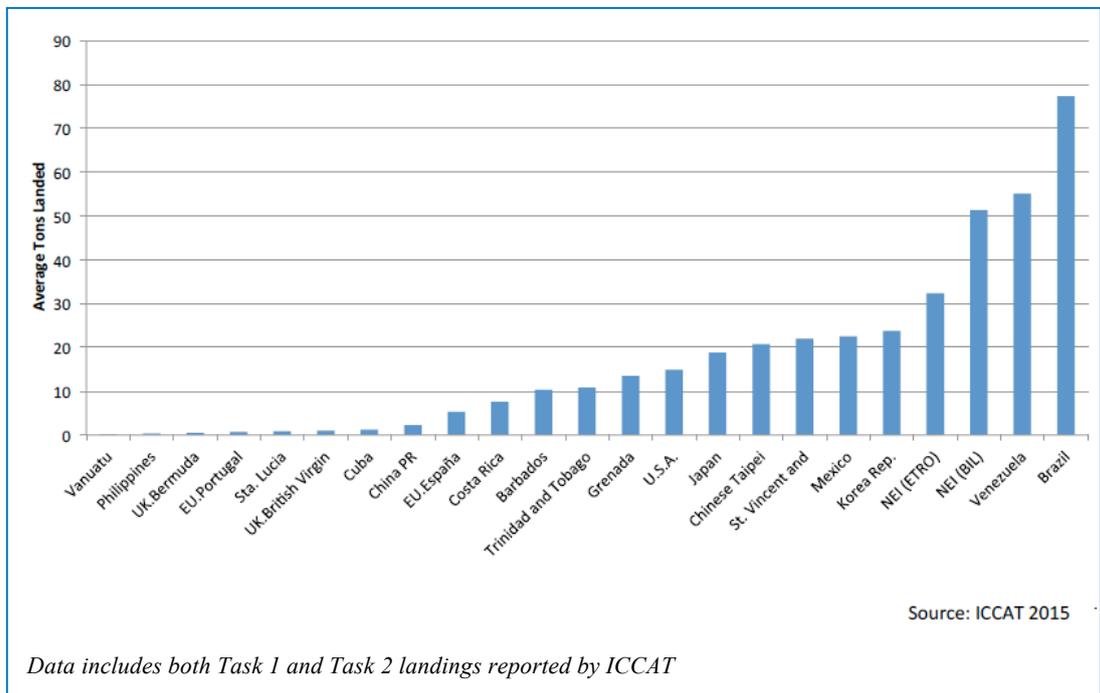


FIGURE 23  
Sailfish landed by country within WECAF region

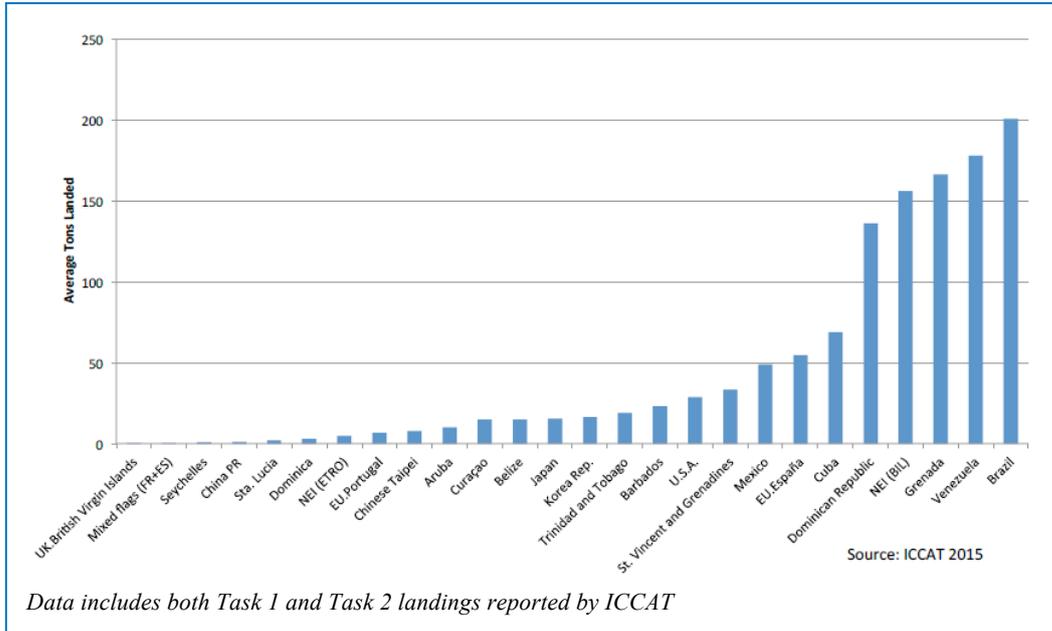
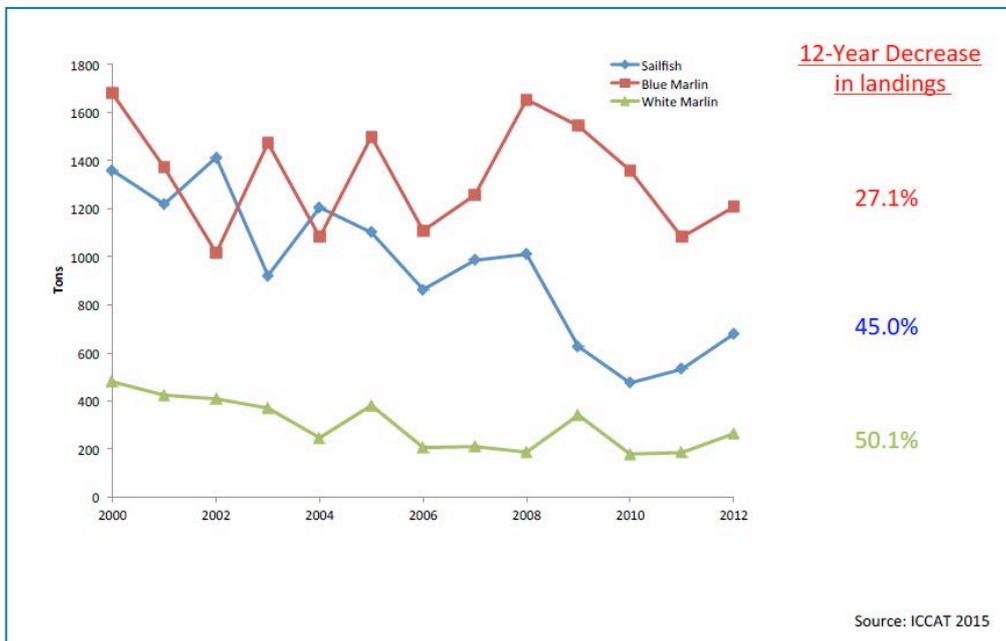


FIGURE 24  
Trends in landings of billfish species reported within WECAFC region. Data from Task 2 spatially-explicit statistics reported by ICCAT within confines of WECAFC spatial area



Moored FADs (mFAD) are widely used in the WECAFC region. Their adoption was technically supported by FAO in the 1980s and followed by other fishery regional organizations. This development in pelagic fisheries prompted great optimism among fishers in the insular regions of the Caribbean Sea. Regional symposia on mFADs were organized by FAO in 1998 and 2004 and many prominent technical and scientific studies have been carried out on mFADs since then. mFADs are used by fishers even if they do not fish exclusively for pelagic fishes. For example, Figure 25 from Mathieu *et al* (2013) shows the percent multi-gear composition in the fishing fleets operating in Martinique and Guadeloupe in 2010. In fact, only 24 percent of the fishers in Guadeloupe used

mFADs exclusively and only 19 percent in Martinique. Fleet sizes in Dominica, Martinique, and Guadeloupe are very numerous (Figure 25) portraying the importance of the mFADs to accomplish catch rates that are economically viable.

The effects and efficiency of mFADs greatly depend on fishing modes and distance from shore. For example, mFAD fishermen in Guadeloupe mainly target dolphinfish (Guyader *et al.*, 2011 and 2013; Mathieu *et al.*, 2013) (Figure 26) using privately owned mFADs by a single fisherman, whereas in Martinique pelagic fishing activities are organized by fisher groups that use fewer mFADs (Figure 27). The species composition in landings from these two places is significantly different. Statistics available for the 2008 dolphin fishing season shows that in Guadeloupe, fishers caught 50 percent of the targeted species and 18 percent of the bycatch was billfish. During the off-season, dolphinfish accounted for only 18 percent of the landings while blue marlin contributed 15 percent to the bycatch. Yellowfin tuna appeared as an important component in the landings, contributing 22 percent in the dolphin season and 49 percent in the off-season. In Martinique, marlin and sailfish represented 41 percent of the landings during the dolphinfish fishing season. During the off-season, marlin and sailfish reached 51 percent of landings while dolphinfish was only 2 percent. Blue marlin is a species that significantly contributes to total landings in the eastern Caribbean region and most of such landings are originated from mFADs. Figure 28 shows that blue marlin landings reported to ICCAT may well reach over 1 200 tonnes with Martinique and Guadeloupe significantly contributed to these landings. The remaining catch statistics originate from Dominica, Aruba, Curacao, Dominican Republic, Cuba, Grenada, St. Vincent and the Grenadines and St. Lucia. However, ICCAT does not identify if blue marlin from “other fleets” is in fact from mFADs, but the ICCAT stock assessment group that met in Mexico in 2014 report that “It is possible that some of these catches correspond to anchored FADs”. The popularity of mFADs throughout the Caribbean community has extended to recreational fisheries due to lucrative catch rates, but this is not without contention. Given the sentiments among commercial fishers that mFADs are proprietary in nature, recreational fishermen in the Caribbean, specifically in the Dominican Republic, have noted that it has become commonplace for commercial fishers (in proximity of mFADs) to commandeer billfish (or any fish) hooked by recreational anglers fishing near mFADs (Marlin Magazine, 2014; *personal communication with anglers*).

FIGURE 25

**FADs are part of all fisher’s activities in Martinique and Guadeloupe (upper figure) and fleet size in Dominica, Martinique and Guadeloupe (lower figure)**

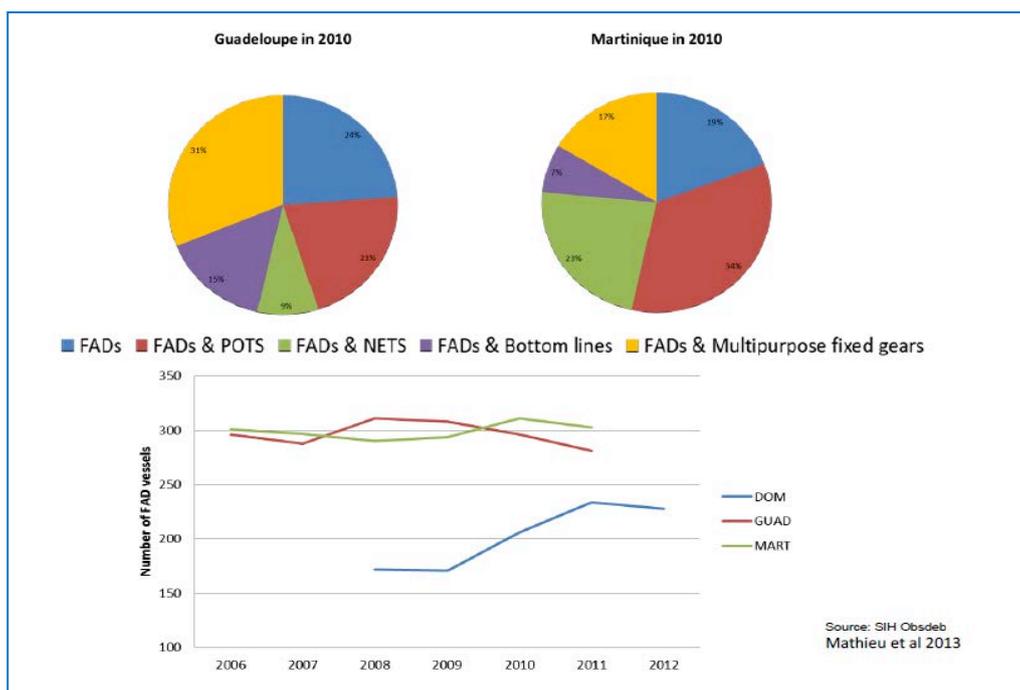


Figure 26

Guadeloupe mFAD fishing grounds and resulting seasonal catch composition in 2008

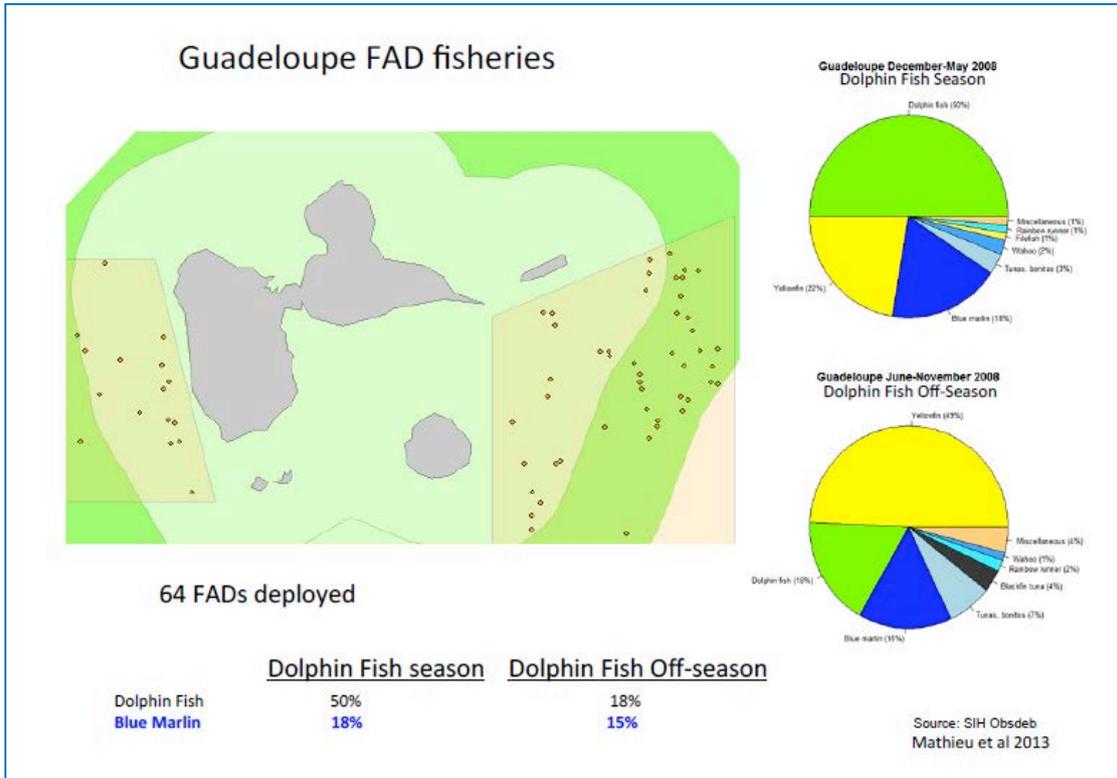


FIGURE 27

Martinique mFAD fishing grounds and resulting seasonal catch composition in 2008

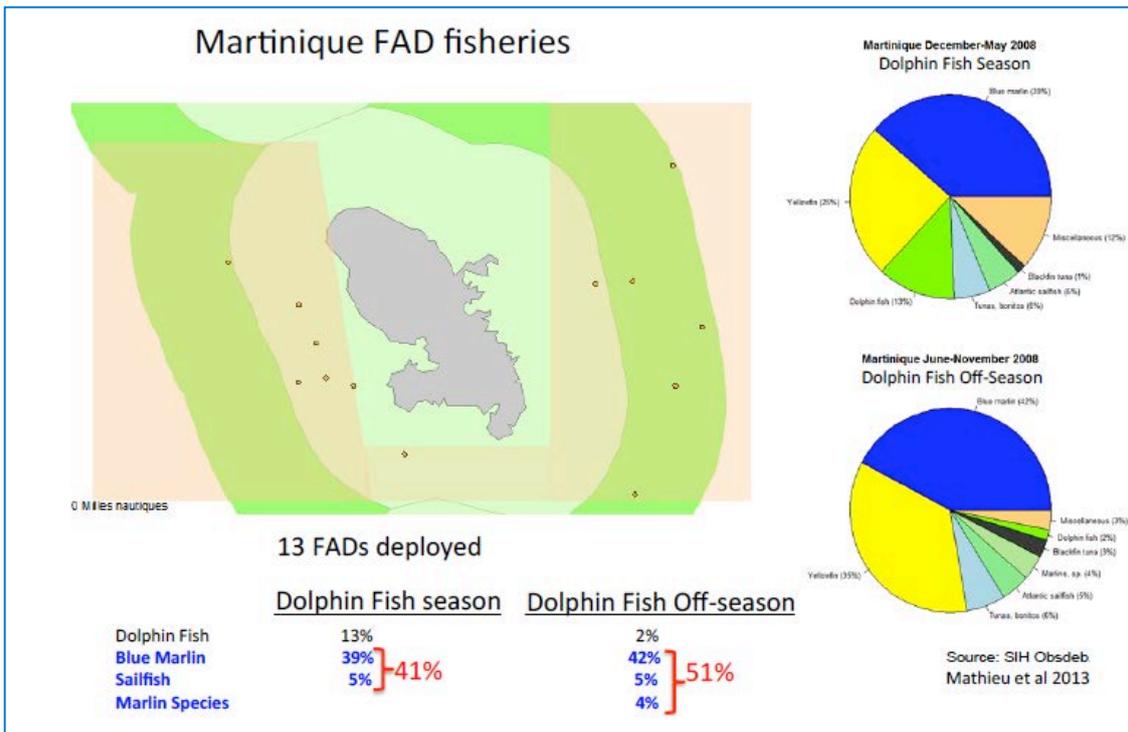
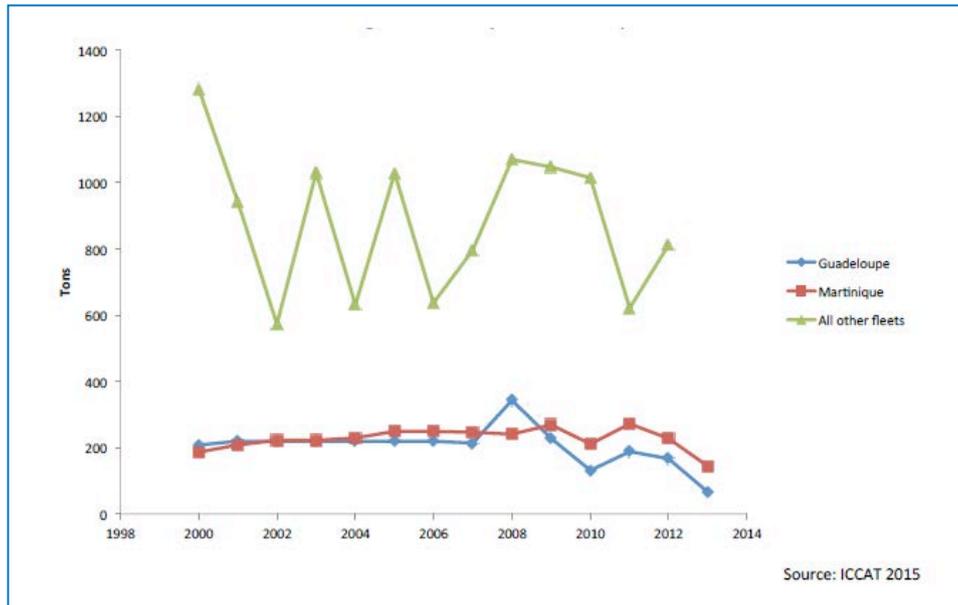


FIGURE 28  
Landings of blue marlin in the WECAFC region with relative reference to landings by Martinique and Guadeloupe fleets. Data from ICCAT



Billfish recreational fisheries were developed in the United States during the early 1930s and have since extended in correspondence to tourism expansion throughout most WECAFC communities within the Caribbean and Latin America. Billfish recreational fisheries often provide substantial economic and social incentives for economies (Ditton and Stoll, 2003) that have marginal values per fish that often exceed those in capture fisheries by orders of magnitude (Ehrhardt and Fitchett, 2008, Report to Government of Costa Rica). The economic and intrinsic value provided by billfish in recreational fisheries as well as the potential added value of billfish in catch-and-release fisheries, due to its low perceived mortality, underscores the importance of billfish as a viable fishery resource. Recreational fisheries have adopted the use of circle hooks and modified fishing practices over time to successfully reduce incidental mortality without any detriment to fishing performance (Prince *et al.*, 2007).

One of the largest social and economic means for which billfish contribute to tourism-based recreational fisheries are tournaments for which large registration entry fees and awards generate incentives for catching billfishes. The vast majority of tournaments are catch-and-release in nature and depend on numbers of fish caught and successfully released, verified by observers and by other means. In 2012 and 2013, there were numerous billfish tournaments per year as shown in Table 3 below from data obtained from the 2014 Stock Assessment and Fishery Evaluation (SAFE) Report for Atlantic Highly Migratory Species. Within US states and islands inside the WECAFC region: North Carolina South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Texas, Puerto Rico, and the US Virgin Islands, there are 143 tournaments with seasons differing by region (Table 3). The number of targeted billfish species in US tournaments by state and island (including Puerto Rico and the US Virgin Islands) is shown in Figure 29. Sailfish tournaments are very significant in the east coast of Florida, particularly in the winter, while blue and white marlin tournaments are consistently important in all the states shown.

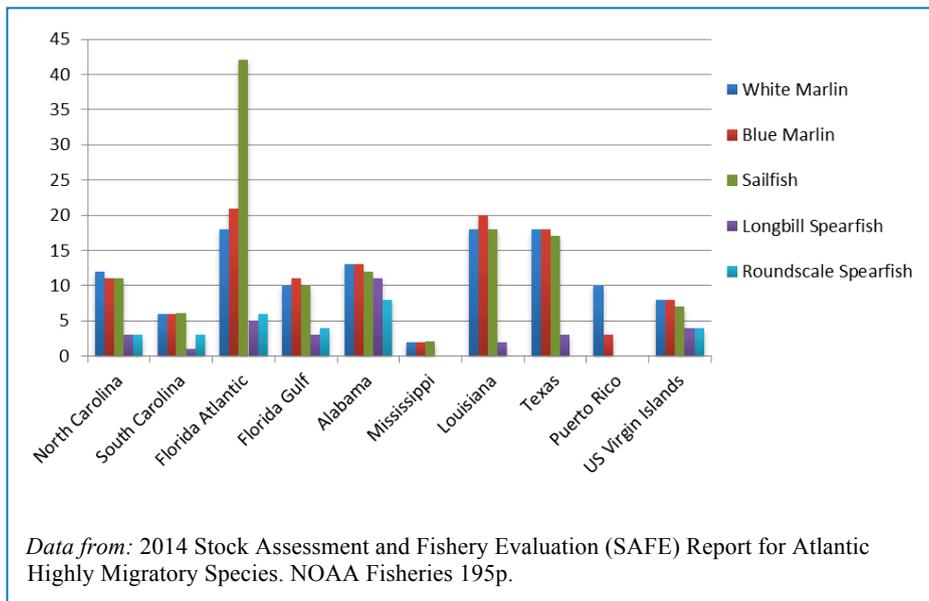
Table 3

Number of US billfish tournaments by month and region within WECAFC region. Data from Figure 8.4 in 2014 Stock Assessment and Fishery Evaluation (SAFE) Report for Atlantic Highly Migratory Species

	South Atlantic (NC to FL)	Gulf Coast (FL to TX)	Caribbean (BA, PR, VI)	TOTAL
January	12	0	0	12
February	2	0	1	3
March	2	0	0	2
April	8	0	1	9
May	7	11	3	21
June	6	13	0	19
July	9	20	2	31
August	3	12	4	19
September	2	2	2	6
October	3	2	5	10
November	2	0	3	5
December	6	0	0	6
<b>TOTAL</b>	<b>62</b>	<b>60</b>	<b>21</b>	<b>143</b>

FIGURE 29

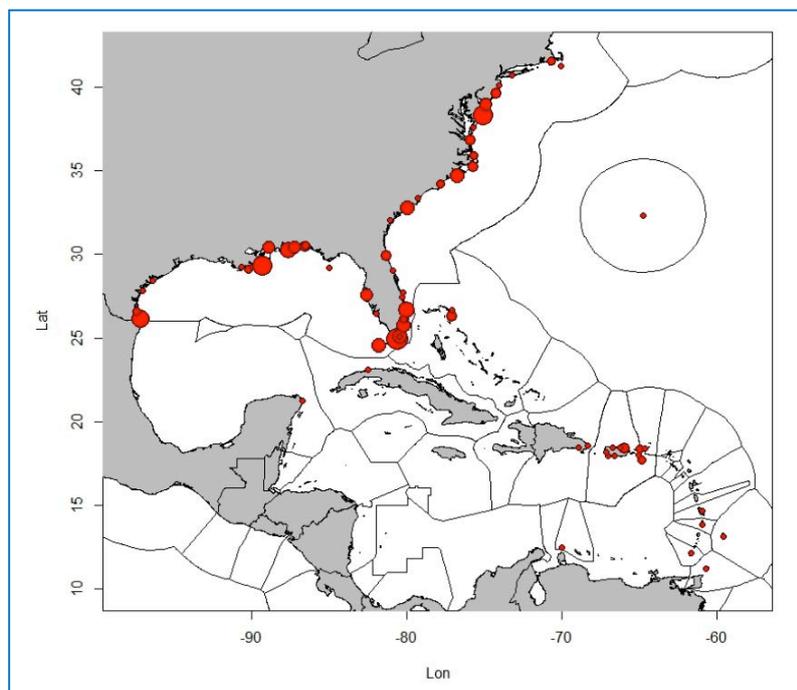
Distribution of the targeted species in billfish tournaments by US state and territory within the WECAFC area



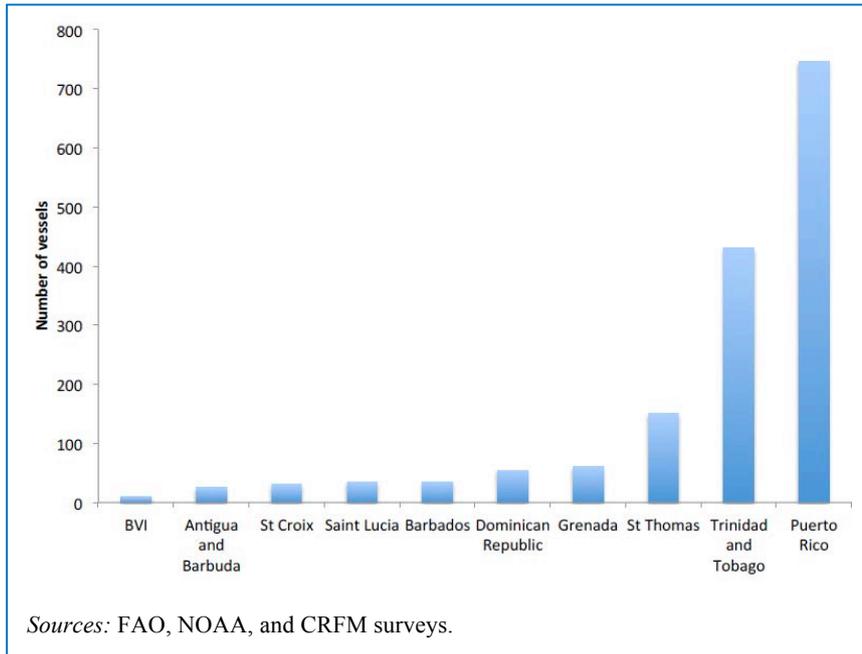
In 2015, over 215 billfish tournaments took place in several localities throughout the WECAFC region (Figure 30). These tournaments have large economic value regarding a highly desirable use of the resource due to the fact that these tournaments are catch-and-release. The number of participant boats in these events in the Caribbean is dissimilar because they depend very much on the number of boats available in the region (Figure 31). However, some participants may travel very long distances in their boats to participate in some of these events. Several surveys have been carried out in Puerto Rico and the US Virgin Islands that provide a general frame to define the importance of the billfish resources in sustaining these events. Figure 32 provides insight on the number of daily blue marlin tournaments trips (number of trips per participant boat multiplied by the number of boats participating) relative to overall Highly Migratory Species (HMS) tournament trips. Of the approximately 600 accumulated fishing trips, some 420 are targeting blue marlin. Most of these trips take place during the period from April to September.

FIGURE 30

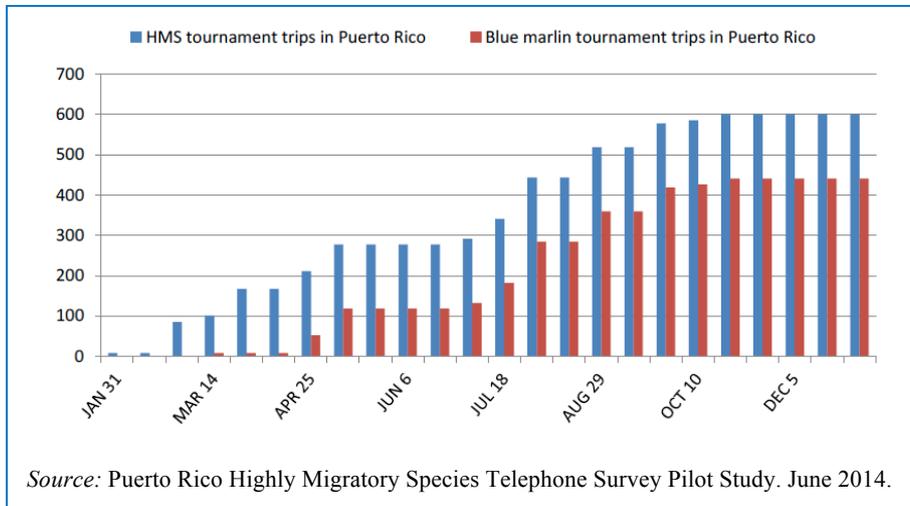
**Distribution and density (circle size) of recreational billfish tournaments in communities within and economic exclusion zones (EEZs) of nations within WECAFC region.**  
**Figure created by authors with tournament information from IGFA and NOAA**



**FIGURE 31**  
**Recreational fleet sizes in the eastern Caribbean Sea**



**FIGURE 32**  
**Importance of blue marlin in the recreational billfish tournaments implemented in Puerto Rico**



The large number of recreational fishers from Puerto Rico frequently visit other countries in the region and significantly target billfish species in their recreational fisheries effort. Out of those species, blue marlin is by far (over 80.6 percent) the most important species, followed by white marlin (44.8 percent), and sailfish (25.4 percent) according to surveys in Puerto Rico (Table 4).

Table 4

**Species targeted by recreational fishers from Puerto Rico when fishing in other countries in the Caribbean region**

Species fished in other countries	Percent of permit holders
Blue Marlin ( <i>M. nigricans</i> )	80.6
White marlin ( <i>T. albidus</i> )	44.8
Sailfish ( <i>I. platypterus</i> )	25.4
Tunas general	7.5
Spearfish ( <i>T. pleugeti</i> )	4.5
Yellowfin tuna ( <i>T. albacares</i> )	4.5
Sharks general	3.0
Albacore tuna ( <i>T. alalunga</i> )	1.5
Blackfin tuna ( <i>T. atlanticus</i> )	1.5
Bigeye tuna ( <i>E. alletteratus</i> )	1.5
Skipjack tuna ( <i>K. pelamis</i> )	1.5

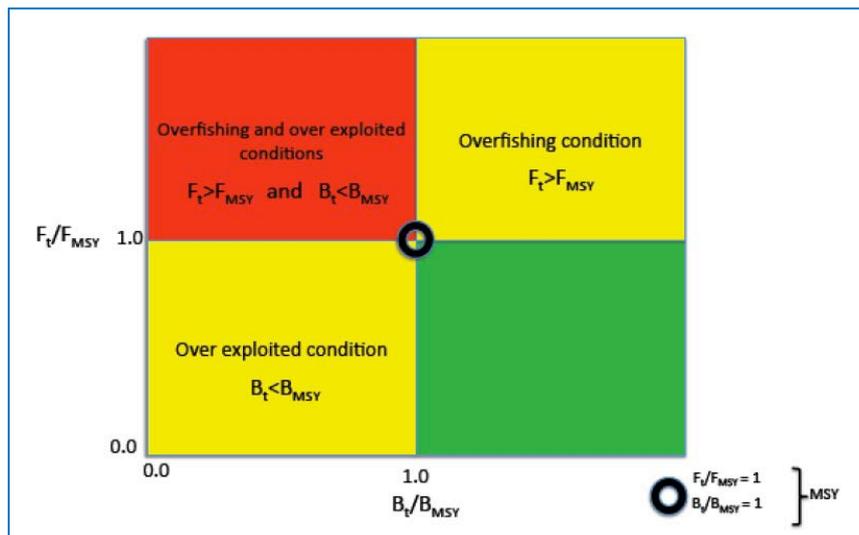
## 4. STATUS OF BILLFISH RESOURCES

### 4.1 Stock assessment data and models

The last assessment for blue marlin was carried out in 2011 and the next assessment is scheduled for 2017. The last assessment for white marlin was in 2012 and the following assessment is scheduled for 2018. Sailfish (including longbill spearfish) was assessed in 2009 and is scheduled for a next assessment in 2016. ICCAT has adopted criteria for declaring the status of exploitation of fish stocks under its jurisdiction and fishery management actions that should be required according to results of mandated stock assessment processes. The criteria consist of a two-way approach, one defining stocks in state of over fishing when the ratio of observed (estimated) fishing mortality rate ( $F$ ) to the rate of fishing mortality at maximum sustainable yield ( $F_{MSY}$ ) is greater than 1 (i.e.  $F/F_{MSY} > 1$ ). The second, when the ratio of observed (estimated) stock biomass ( $B$ ) to biomass at maximum sustainable yield ( $B_{MSY}$ ) is lower than 1 (i.e.  $B/B_{MSY} < 1$ ), then the stock may be declared overfished. Therefore, an under-exploited stock should reflect levels of  $F/F_{MSY} < 1$  and levels of  $B/B_{MSY} > 1$  to not be in violation of fishery benchmarks requiring management action. Relationships between the both benchmarks are depicted in so-called 'Kobe phase plots' to graphically interpret the status of the fishery (Figure 33).

FIGURE 33

#### Kobe plot depiction of $F/F_{MSY}$ and $B/B_{MSY}$ with status inferences (ICCAT Manual)

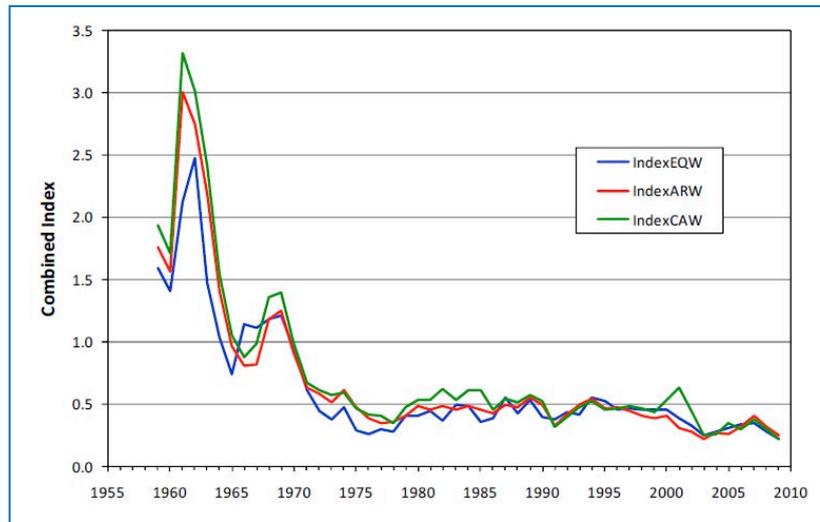


The main task of the ICCAT stock assessment process is to estimate such ratios and make projections of the effects of different fishing mortality scenarios (resulting in proposed annual quotas as a potential mechanism to control fishing mortality) for either maintenance or recovery of the stocks. To simplify technical discussions at the Commission level, ICCAT-associated stock assessment scientists decided to adopt mandated standardized stock assessment frames such that results are comparable among stocks and between consecutive assessments of stocks. Such standardization helps defining standardized data gathering needs as well for data acquisition procedures follow requested levels of stock assessment data needs and quality of the data needed. The stock assessment algorithms presently utilized include: 1) a non-equilibrium production model (A Stock Production Incorporating Covariates, ASPIC) that uses total landings and catch per unit of effort (Prager, 1992, 1994), and 2) Stock Synthesis III (SS3, version 3.23b) stock assessment framework that uses a statistical catch-at-age approach to create a population time-series that best fits the given observations using maximum likelihood as the fitting objective (Methot and Wetzel, 2013). ASPIC and its related surplus production alternatives have simpler data requirements; therefore they are more applicable in billfish fisheries. Data requirements and options for ASPIC are minimally two of the following: catch, effort, or CPUE indices, sometimes with a priori estimates of carrying capacity,  $K$ . For SS3, data requirements are



FIGURE 35

### Combined standardized CPUE indices for multiple scenarios of pooling catch



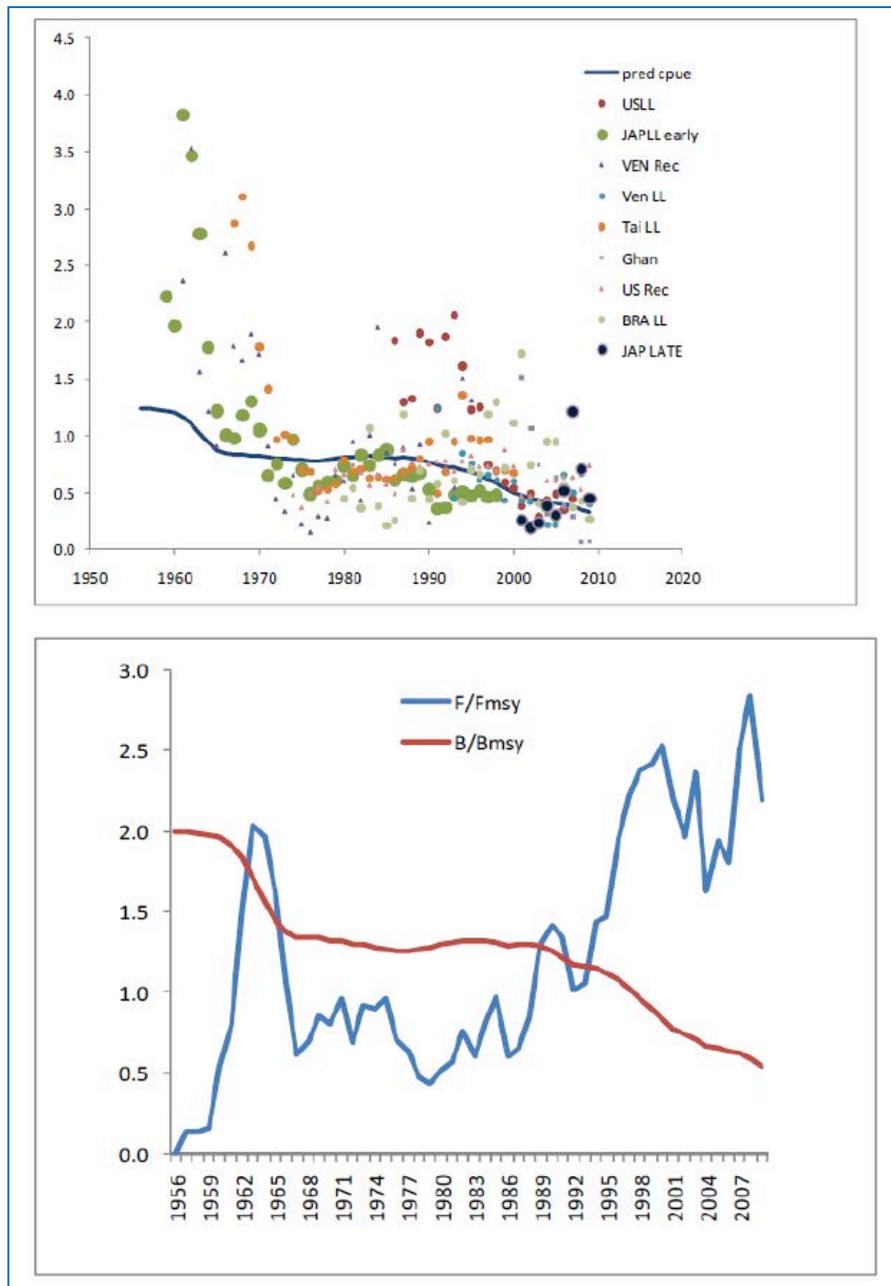
Model configurations for the implementation of ASPIC used in the 2011 blue marlin stock assessment were the same from 2000 assessment for purposes of continuity. ASPIC runs for blue marlin assumed one Atlantic stock and began in the year 1956 from provided catch and CPUE indices and assumed that carrying capacity was universal among each model run. ASPIC runs also utilized bootstrapping features in the program to develop confidence intervals for annual biomass and mortality benchmarks.

The assessment group reported that ASPIC failed to converge when CPUE series were fit under the 'base case' equal weights scenario and also under weighted CPUE proportional to area of the fishery. The assessment group also elected to run ASPIC using the three combined indices (Figure 35), which successfully converged. However, it was noted that parameter values estimated were considered to be unrealistic for carrying capacity,  $K$ , and for intrinsic population growth rate,  $r$ . The assessment group suggested that lack of correlations among CPUE trends intra-annually likely contributed to issues of non-convergence and unrealistic parameter estimates. To mitigate these perceived limitations, alternative ASPIC runs were made under two assumptions: 'low productivity' and 'high productivity'. For assumptions under the low productivity ASPIC runs, CPUE were weighted equally and  $K$  was fixed to 100 000 tonnes to achieve convergence. Under assumptions of 'high productivity', CPUE indices were weighted by area covered by the fishery and indices from Ghana and Brazil were excluded since they were negatively correlated with other indices. Furthermore, Chinese Taipei and Japanese indices were split between pre and post-1980 due to perceived transitional changes in catchability due to targeting of deeper water bigeye tuna in those fleets.

The assessment group considered that the 'low productivity' run was having issues dealing with catch series not being in agreement with some CPUE indices. However, when some of the CPUE series were excluded, ASPIC converged to a solution and the remaining CPUE series become somewhat more informative about stock productivity ('high productivity' run). Regardless, biomass in both cases was estimated to be below  $B_{MSY}$  and the fishing mortality exceeding  $F_{MSY}$  in either run. Differences in the estimates of  $MSY$  (2 700 tonnes and 4 300 tonnes) were quite striking between the low and high productivity runs, respectively. The corresponding  $r$ -values for these two runs were very different, 0.11 and 0.65, respectively. The 'high productivity' ASPIC run is depicted in Figure 36

FIGURE 36

**High productivity' ASPIC runs with the predicted CPUE trend fitted to observed CPUE (top) and resulting mortality and biomass benchmarks (bottom)**



The statistically integrated SS3 model runs for blue marlin were run under catch partitioned by gear in the same manner as the ASPIC runs, growth models for both sexes were estimated within SS3, a maturity function was input, sex ratios at length from existing studies in US recreation fisheries and Venezuela gillnet and longline fisheries were input, length compositions by each gear (except purse seine), and release rates of blue marlin by year in recreational fisheries were used. The SS3 model assumed annual time steps under one area and two sexes, used a fixed natural mortality of 0.139, freely estimated growth parameters and recruitment by SS3, and assumed a constant catchability by gear.

Model runs using SS3 produced growth parameters by sex that agreed with what was perceived to be biologically true estimates according to the assessment group and coincided with growth parameters for blue marlin in the Pacific (Hill *et al.*, 1989) and agreed with sex ratio observations at length.

Length composition data found no meaningful signals discern annual recruitment, although the data found no issues with selectivity given consistencies by year. The assessment group was satisfied by statistical fits to the data and with spawning stock (Figure 37) recruitment (Figure 38) biomass and mortality benchmarks (Figure 39). The integrated SS3 model resulted in an estimate of maximum sustainable yield of 2 837 tonnes (sd = 246 t), which closely resembles the estimates of the ‘low productivity’ run in ASPIC. The resulting estimate of stock status from SS3 model were that the stock is currently overfished ( $B/B_{MSY} = 0.670$ , sd = 0.071) and undergoing overfishing ( $F/F_{MSY} = 1.633$ , sd = 0.263).

FIGURE 37

### Estimates of spawning stock biomass as estimated by SS3 integrated model

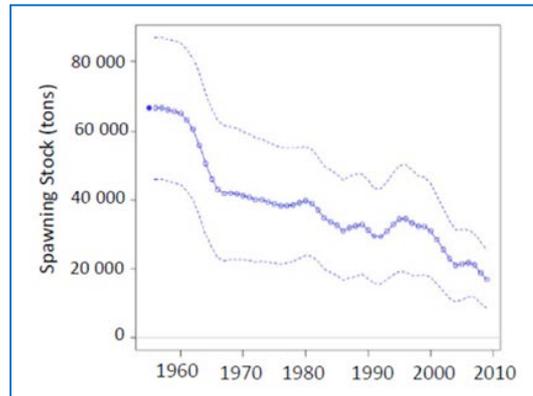


FIGURE 38

### Recruitment and variability by year for blue marlin as estimated by SS3 model

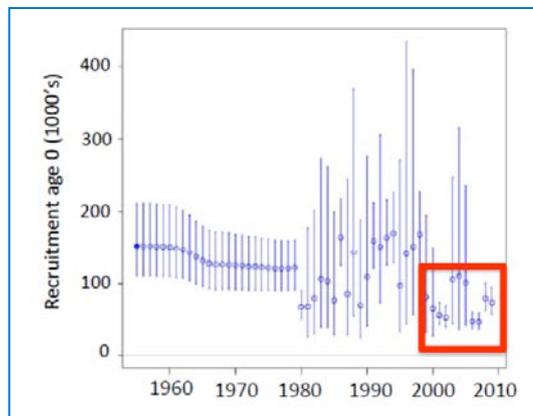
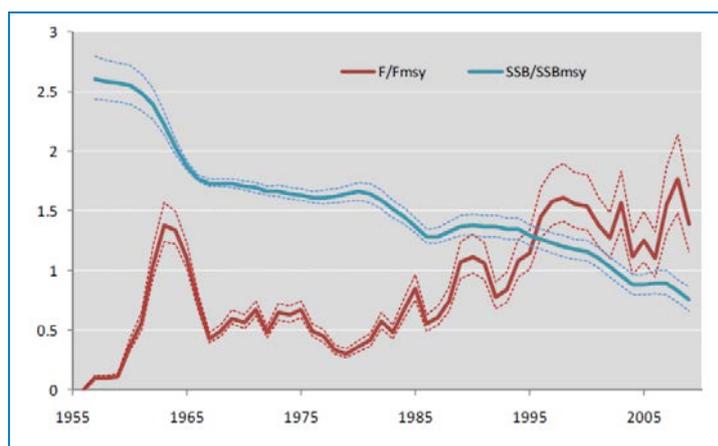


FIGURE 39

### Benchmarks of $F/F_{MSY}$ and $B/B_{MSY}$ by year as estimated by SS3 model



Results from the stock assessment models produced likely benchmarks of mortality and biomass by year. Using results from the SS3 model, the Kobe plot in Figure 40 depicts a blue marlin stock over the time series moving into a situation that is both overfished and had been experiencing overfishing for several years. Fifteen year projections for the blue marlin stock from 2012 to 2026 shows an increasing biomass relative to biomass at MSY if total yield is 2 000 tonnes or less and yields of 2 500 tonnes keeping the stock stable (Table 5). Table 6 depicts a Kobe strategy matrix predicting the probability of achieving a ratio of benchmarks of  $F/F_{MSY}$  and  $B/B_{MSY}$  to equal 1 given levels of total allowable catch (TAC). A TAC of less than 2 000 yields a 50 percent chance of reaching these benchmarks in 15 years.

FIGURE 40

**Kobe plot of blue marlin with current status (in green diamond) as overfished and experiencing overfishing. Blue line depicts the trajectory of benchmarks throughout time**

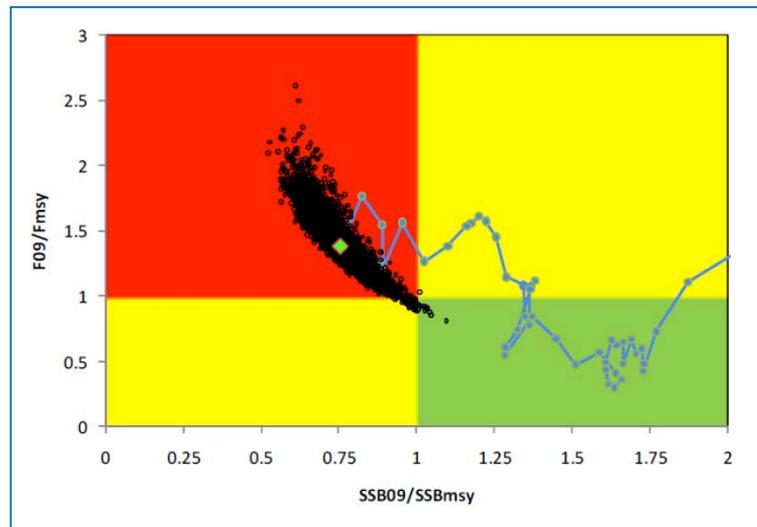


Table 5

**Benchmarks of  $B/B_{MSY}$  over time given total allowable catch (TAC)**

Year	Catch 0	500	1000	1500	2000	2500	3000	3500	4000
2010	0.730019	0.730319	0.730319	0.730319	0.730319	0.730319	0.730319	0.730319	0.730319
2011	0.705949	0.705949	0.705949	0.705949	0.705949	0.705949	0.705949	0.705949	0.705949
2012	0.684518	0.684518	0.684518	0.684518	0.684518	0.684518	0.684518	0.684518	0.684518
2013	0.747284	0.735067	0.722912	0.710816	0.69857	0.6866	0.674937	0.662819	0.650665
2014	0.807427	0.78413	0.759727	0.73593	0.711736	0.687999	0.663826	0.638816	0.614842
2015	0.869686	0.832156	0.795515	0.759411	0.722677	0.686481	0.650552	0.61429	0.578451
2016	0.929767	0.880576	0.832159	0.784004	0.734573	0.686935	0.638708	0.590197	0.540989
2017	0.994037	0.932765	0.872557	0.810334	0.748807	0.687464	0.626182	0.564506	0.503026
2018	1.05914	0.98465	0.91065	0.839011	0.764148	0.689571	0.614619	0.53965	0.464618
2019	1.121755	1.03784	0.951883	0.866153	0.779697	0.691005	0.60246	0.513194	0.42396
2020	1.18609	1.089965	0.993575	0.894843	0.794923	0.690961	0.587983	0.485334	0.379811
2021	1.245605	1.139545	1.03127	0.919711	0.807669	0.691898	0.572685	0.455044	0.334355
2022	1.3056	1.18798	1.06985	0.948173	0.82092	0.691317	0.5583	0.425262	0.289528
2023	1.36488	1.239005	1.108815	0.972672	0.837039	0.691292	0.543366	0.391995	0.241419
2024	1.421225	1.285975	1.146675	1.001305	0.851388	0.692626	0.529049	0.358837	0.194934
2025	1.47461	1.334295	1.18296	1.02989	0.865275	0.696268	0.513041	0.3256522	0.14728
2026	1.525875	1.377005	1.22217	1.05738	0.884099	0.696307	0.496624	0.28923	0.10432

Table 6

**Kobe strategy matrix projecting the probability of achieving a ratio of benchmarks of  $F/F_{MSY}$  and  $B/B_{MSY}$  to equal 1 given levels of total allowable catch (TAC) for 15 years**

Year	0	500	1 000	1 500	2 000	2 500	3 000	3 500	4 000
2012	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013	2%	2%	1%	1%	1%	1%	0%	0%	0%
2014	4%	6%	4%	3%	2%	1%	1%	0%	0%
2015	19%	13%	9%	6%	3%	2%	1%	0%	0%
2016	33%	23%	15%	9%	5%	3%	1%	0%	0%
2017	49%	35%	22%	13%	7%	3%	2%	0%	0%
2018	63%	47%	31%	18%	10%	4%	2%	0%	0%
2019	74%	58%	40%	24%	12%	5%	2%	1%	0%
2020	81%	67%	49%	30%	16%	6%	2%	1%	0%
2021	74%	56%	36%	18%	7%	2%	0%	0%	0%
2022	92%	80%	63%	41%	21%	8%	3%	0%	0%
2023	94%	84%	68%	46%	24%	9%	3%	0%	0%
2024	96%	88%	73%	50%	27%	10%	3%	0%	0%
2025	97%	91%	77%	55%	29%	11%	3%	0%	0%
2026	98%	93%	81%	59%	32%	12%	3%	0%	0%

#### ***White Marlin (Stock assessment May 2012)***

Catch and effort records for white marlin date back to the 1950s. Recent revelations in the literature indicate that misidentification of roundscale spearfish as white marlin in landings may create issues for stock assessments of white marlin (Beerkircher *et al.*, 2009); although measures have been made to statistically account for such issues. Standardized CPUE indices of abundance for white marlin depict a decreasing trend in the Japanese longline fishery from the early 1960s to 1990s; whereas nine other CPUE indices seemingly remain stabilized with lots of interannual ‘noise’ (Figure 41). With exception of the Japanese longline data, nine other CPUE indices display little contrast from the 1970s to 2010. The assessment group noted that some CPUE indices display interannual variation that may not be biologically reflective of the stock. The assessment group also concluded that CPUE from Chinese Taipei longline fleets were declining due to management action requiring live discards, granting an overall reduction in catch. Catch data were partitioned by gear groups: longline, gillnet, purse seine, and recreational catch. Catch of longline fisheries used in the stock assessment were projected for each year since 1997 as reported catch (‘low’) due to the perception of unreported discards, an ‘upper’ estimate based on available comparative catch rates for retained and total catch for each longline fleet after 1997, and a ‘middle’ estimate which is simply the mean of the ‘low’ and ‘upper’ estimate of catch (Figure 42). These CPUE indices and catch series were applied and fit in two methods: ASPIC non-equilibrium production model and an age-structured SS3 model.

FIGURE 41  
 CPUE indices for white marlin used in the assessment methods

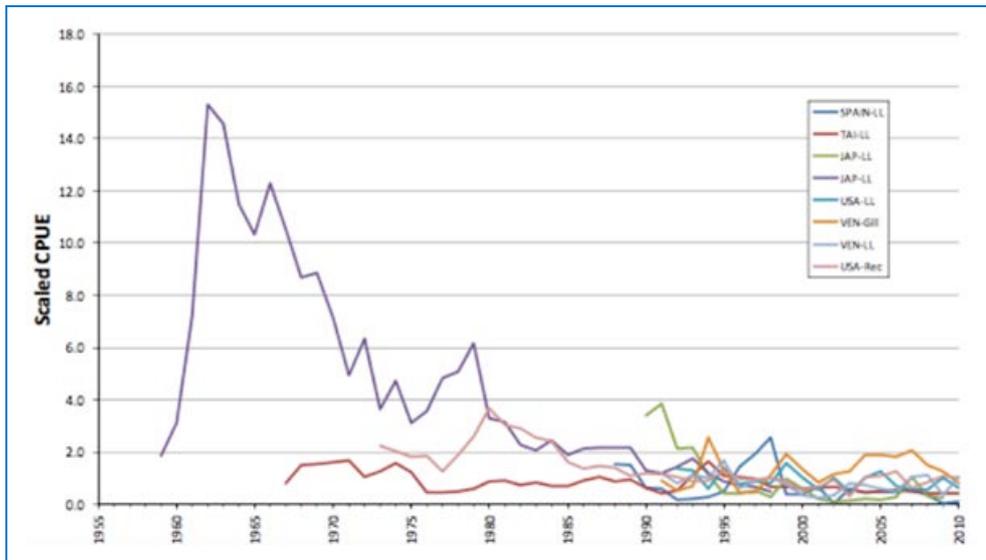
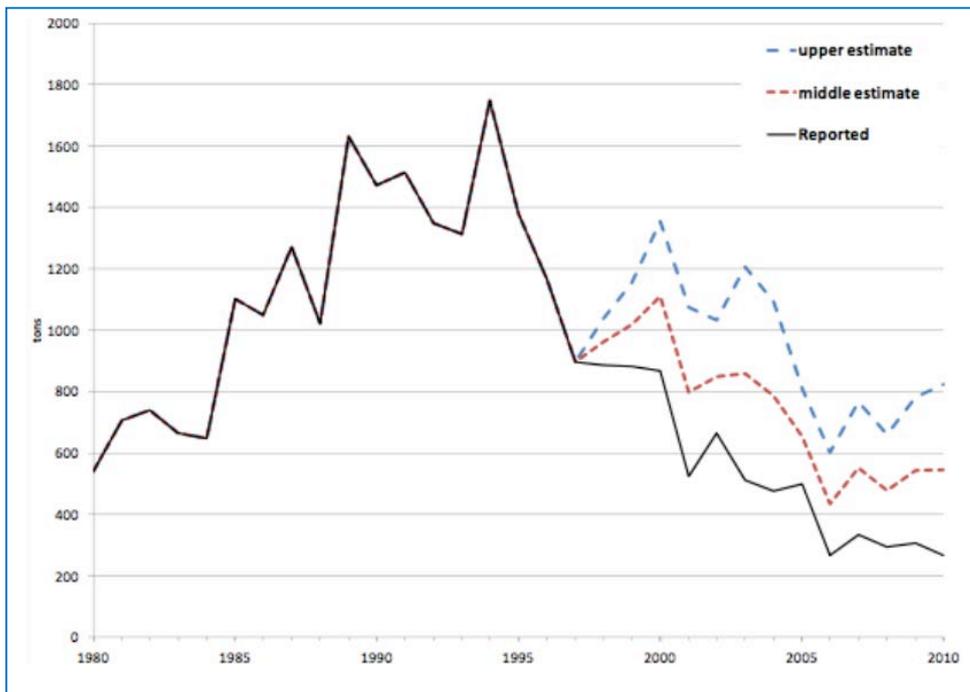


FIGURE 42  
 Reported landings and estimates of cryptic landings (unreported) as a 'middle' and 'upper' estimate

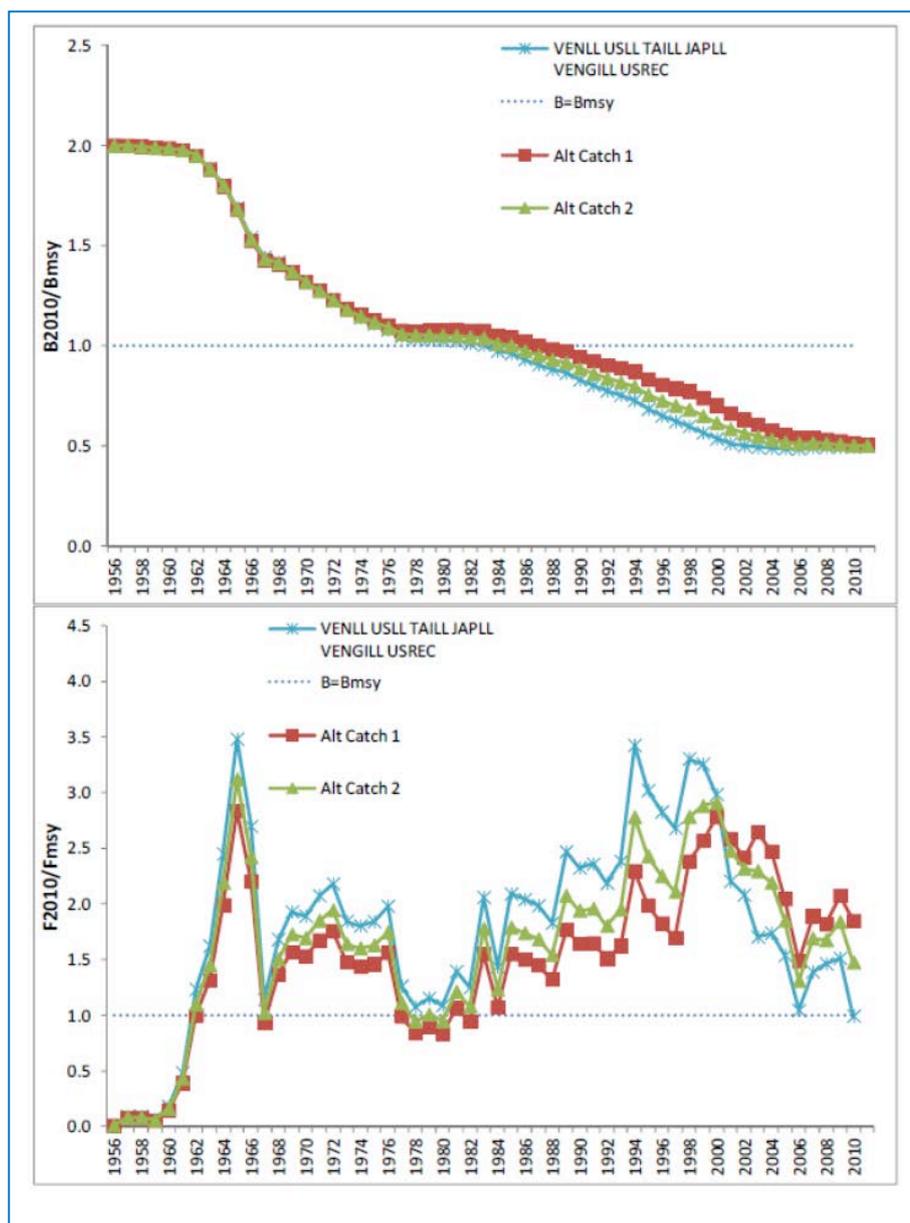


ASPIC runs were implemented for nine CPUE indices and the catch series, excluding Spanish longline indices. Six CPUE series were ultimately selected for use in the ASPIC analyses: Venezuela longline, Venezuela gillnet, US longline, US recreational, Japanese longline, and Chinese Taipei longline. The ratio of biomass at year 1 to carrying capacity was fixed to 1.0 and was not estimated by ASPIC. If CPUE indices did not converge initially, catchabilities were fixed to values estimated if that series were run singularly in ASPIC. Benchmarks from ASPIC runs using the six optimal CPUE, assuming a 'low' productivity stock (using reported catch series) suggested a median MSY of 874 tonnes with estimate 90 percent confidence intervals of 795 to 976 tonnes and an extremely low mortality benchmark ( $F_{MSY} = 0.03$ ). Such approach suggests that the stock has been slowly declining from its

virgin state ( $K = 54\,480$  tonnes). The median biomass ratio in 2011 of 0.50, with 10 and 90 percentiles of 0.42–0.60 depicting that the stock remains very much overfished (Figure 43). The median fishing mortality ratio was 0.99 with 90 percent confidence intervals of 0.75 and 1.27, which is indicative that overfishing was probably not occurring in 2010 (Figure 43). If recent catches run in ASPIC were to be in the ‘upper’ estimate, the estimated MSY would be at around 1 000 tonnes, just marginally larger than using reported catch. Current fishing mortality ratios, however, would be greater than 1 which indicates that overfishing was still occurring in 2010.

FIGURE 43

**Benchmarks of  $B/B_{MSY}$  (top) and  $F/F_{MSY}$  (bottom) for white marlin by year as estimated by ASPIC under scenarios of reported catch (blue), ‘upper’ estimates of catch (red), and ‘middle’ estimates of catch (green)**



Use of SS3 was implemented in the same vein that it was successfully run for blue marlin in 2011. Catch series in four gear types was implemented with possible scenarios of catch for longline fisheries ('low', 'middle', and 'upper' estimates of catch). Length compositions for each of these catch series, with exception of purse seine gears, were also implemented and revised by the assessment group. Growth inputs needed for white marlin in a fully integrated SS3 model were based on Drew (unpublished) hard part analyses and estimates of age at length from Die and Drew (2008). Parameters on maturity were from Arocha and Barrios (2009). Recruitment of white marlin in SS3 was assumed to hold a Beverton and Holt (1957) density dependent function. The stock was assumed to be at an unfished nascent state in the first year of reported catch and CPUE indices. Recruitment trends estimated for the 55 year time series saw a nearly 80 percent decline in recruitment, however, this trend has very wide confidence intervals (Figure 44). The best fitting SS3 run resulted in an MSY of 1 604 tonnes (sd= 28 tonnes). The resulting estimate of stock status from the base case model is that the stock is currently highly overfished ( $B/B_{MSY} = 0.322$ ,  $sd = 0.046$ ). However, results from the best case SS3 run indicates the stock is not currently experiencing overfishing ( $F/F_{MSY} = 0.720$ ;  $SD = 0.105$ ). The steep decline in biomass can be depicted from SS3 results in Figure 45). ASPIC results and those from SS3 are compared in Figure 46. It shall be noted that  $F/F_{MSY}$  estimates may depart from the apparent biomass and recruitment trends and may have contrarian conclusions with depletion of biomass. There is a decreasing trend of  $F/F_{MSY}$  towards 1.0, implying that both methodologies indicate that the condition of overfishing is gradually ameliorated. However, the condition of this stock being overfished persists for the last two decades. These are contradictory results that are not elucidated in the stock assessment reports.

FIGURE 44

**Recruitment of white marlin by year freely estimated from SS3 best case run and 95 percent confidence interval**

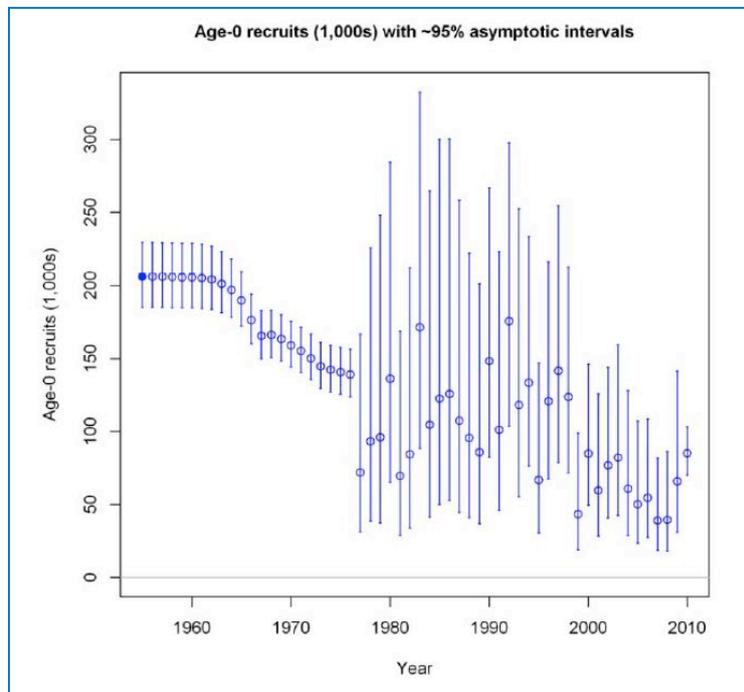
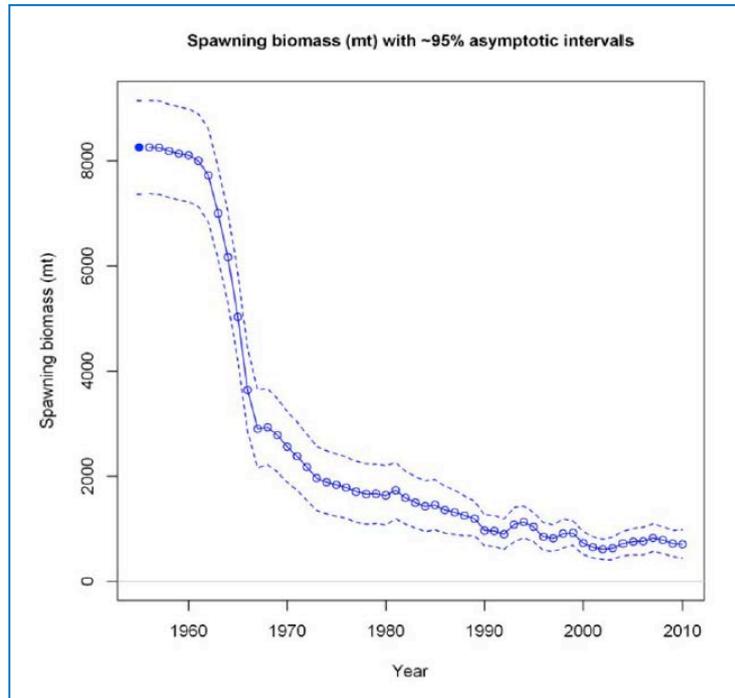


FIGURE 45

**Spawning biomass of white marlin estimated by year from best case SS3 run**



Estimates of mortality benchmarks and projections using estimates from best fits of SS3 runs are slightly more optimistic than those estimated from ASPIC while biomass estimates are less optimistic in the SS3 approach (Figure 46). A Kobe plot of benchmarks for white marlin for the most recent years: 2006 to 2010, indicated that the fishery is overfished and most experiencing heavy exploitation—although not all years have exceeded the threshold (Figure 47). Despite the numerous runs of SS3 and ASPIC, the assessment group did not provide projections of benchmarks under levels of TAC. Using an unverified (by ICCAT) Bayesian production model and using current catch estimates as TAC, it can be inferred that  $B/B_{MSY}$  estimates will continue to decline while TACs under 800 tonnes will stabilize or even increase  $B/B_{MSY}$  estimates over time.  $F/F_{MSY}$  ratio estimates will continue to increase unless TACs are set to under 600 tonnes (Figure 7 and Figure 8, p. 47, Report of the 2012 White Marlin Stock Assessment Meeting).

FIGURE 46

Benchmarks of  $F/F_{MSY}$  (top) and  $B/B_{MSY}$  (bottom) for white marlin by year as estimated by best fits of ASPIC and SS3 model, for comparison

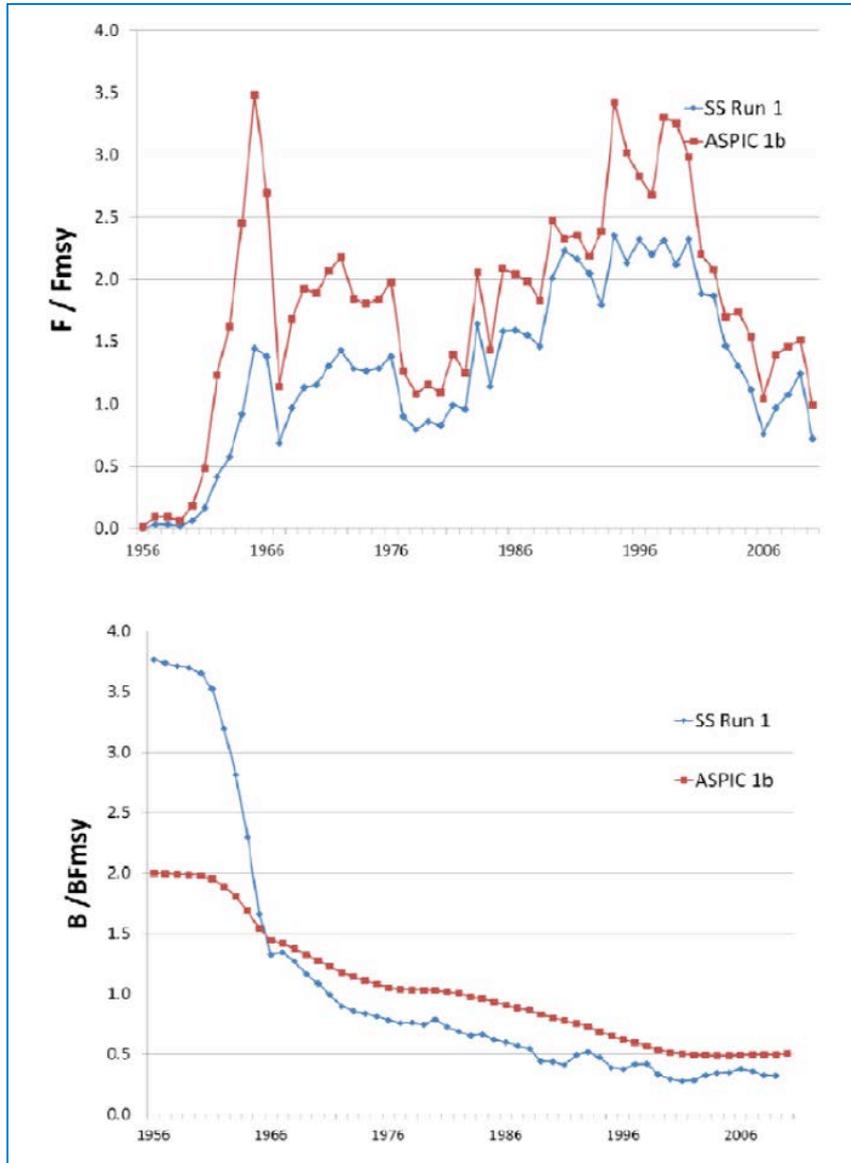
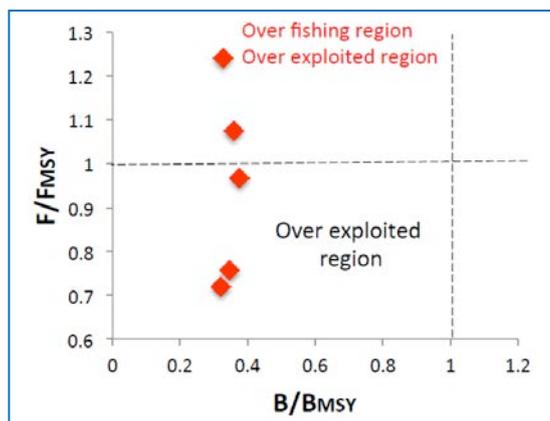


FIGURE 47

Kobe plot of white marlin with most recent estimates of  $F/F_{MSY}$  and  $B/B_{MSY}$  from 2006 to 2010 (in red diamond) from the best case SS3 model runs as overfished and experiencing overfishing



### ***Sailfish (Stock assessment June, 2009)***

Given the more coastal nature of the sailfish, the species was assessed by ICCAT as two separate stocks- an eastern Atlantic and a western Atlantic stock. For sake of brevity and emphasis on billfish in the WECAFC region, this desk study will focus on the western stock. CPUE indices in the western Atlantic used included a Japanese longline series from 1967–1993, a Japanese longline series form 1994–2007, US recreational billfish survey series, US longline series, Chinese Taipei intermittently reported longline indices, Venezuela recreational series, Venezuela gillnet series, Venezuela longline, Brazil recreational series, and a Brazil longline series. Catch in 5x5 degree grids reported to ICCAT for each of the fisheries were used in analyses to weight the CPUE indices by catch and by area. Single indices for the western stock were used by the aforementioned indices under the following scenarios (Figure 48): unweighted (CUW), weighted by annual catch in the each fleet (CCW), and weighted by area as number of 5x5 degree grid squares fished by each fleet in each year (CAW). Production modeling was used as an assessment tool using ASPIC for Schaefer-type of modeling, Microsoft Excel programmed Fox and Schaefer production models, and a Bayesian surplus production model (Andrade and Kinas 2007). Biomass at year 1 in earliest series in production model runs were assumed to be equal to or near K ( $B1/K = 1.0$ ). ASPIC runs were conducted by participants and a total of 15 cases were carried out for the western stock and along with 8 for the eastern Atlantic stock (Table 7). Outputs of benchmarks are included in Table 8.

FIGURE 48

### **Combined CPUE indices for sailfish in the western Atlantic stock**

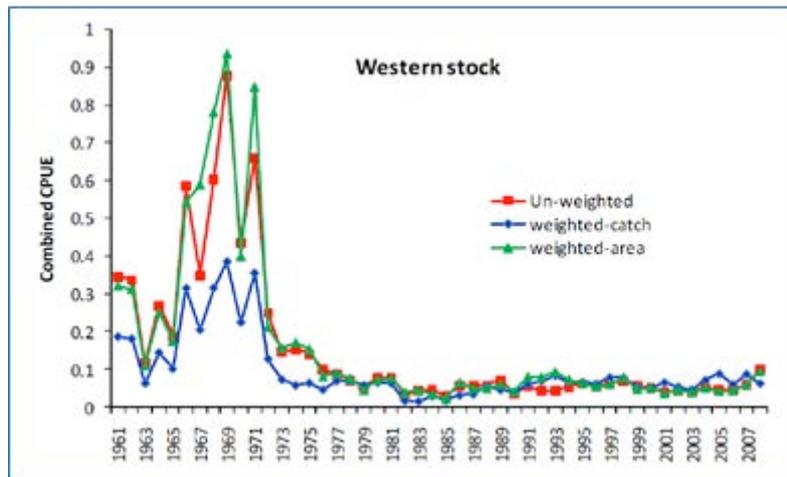


Table 7

**ASPIC runs for sailfish at the ICCAT 2009 sailfish assessment by author, case identification, option (discrete fits or bootstrapped), by stock, and indices used**

Author	Case	Version	Option	Stock	Indices Used
Goodyear	G1	5.16	FIT	W	CAW
Goodyear	G2	5.16	FIT	W	CCW
Goodyear	G3	5.16	FIT	E	CAW
Goodyear	G4	5.16	FIT	E	CCW
Goodyear	G5	5.16	FIT	W	CUW
Goodyear	G6	5.16	FIT	E	CUW
Ortiz	O1	5.33	FIT	W	JAPLL3
Ortiz	O2	5.33	BOT	W	JAPPL3,USLL2,BRZLL,VENLL,KORLL
Ortiz	O3	5.33	BOT	E	JAPPL1,JAPLL2,CIVAR,SENAR,GHNGL
Ortiz	O4	5.33	FIT	E	JAPPL1,JAPLL2
Ortiz	O5	5.33	BOT	W	USRR1, USRR2, BRZRR, VENRR
Ortiz	O6	5.33	FIT	W	JAPLL3, USLL2, BRZLL, VENLL, KORLL, USRR1, USRR2, BRZRR, VENRR
Ortiz	O7	5.33	BOT	E	JAPLL3, CIVAR, SENAR, GHNGL
Ortiz	O8	5.33	BOT	E	CIVAR, SENAR, GHNGL
Ortiz	O9	5.33	BOT	W	JAPLL2, USLL2, BRZLL, VENLL, USRR1, BZRR, VENRR, VENGN, TAILL
Ortiz	O10	5.33	FIT	W	JAPLL1, USLL2, BRZLL, VENLL, USRR1, BZRR, VENRR, VENGN, TAILL
Ortiz	O11	5.33	IRF	W	USRR1, USRR2, BRZRR, VENRR
Ortiz	O12	5.33	IRF	W	JAPPL3, USLL2, BRZLL, VENLL, KORLL
Ortiz	O13	5.33	FIT	W	JAPPL1, JAPPL2, USLL2, BRZLL, VENLL, USRR1, BZRR, VENRR, VENGN, TAILL
Wor	W1	5.33	FIT	W	CAW
Wor	W2	5.33	FIT	W	CCW
Wor	W3	5.33	FIT	W	CUW
Fitchett	F1	5.24	BOT	E	CUW
Fitchett	F2	5.24	BOT	E	JAPLL1/JAPLL2, CIVAR, SENAR, GHNGL(*)

Table 8

**Results for of  $F/F_{MSY}$  and  $B/B_{MSY}$  ratios for 2007 estimated by ASPIC**

Stock	Case	Estimate	MSY(t)		Fratio		Bratio			
			25 %	75%	Estimate	25%	75%	Estimate	25%	75%
<b>East</b>										
	g3	2 340			3.77			0.14		
	g4	76			185.90			0.09		
	g6	2 105			2.51			0.28		
	o3	5 072			0.27			1.73		
	o4	4 949			0.17			1.83		
	o7	2 247	2 131	2 359	0.62	0.57	0.76	1.15	1.00	1.25
	o8	1 868	455	1 897	1.58	1.17	27.81	0.53	0.00	0.62
	f1	2 106	1 713	2 341	3.89	2.64	5.65	0.24	0.12	0.39
	f2	2 460	2 179	2 481	2.26	1.71	2.76	0.26	0.17	0.34
<b>West</b>										
	g1	100			3.07			0.35		
	g2	873			1.40			0.94		
	g5	284			8.63			0.45		
	o1	1 220			0.67			1.25		
	o2	1 455	1 198	1 550	0.59	0.47	0.90	1.25	0.93	1.41
	o5	1 062	291	1 154	0.81	0.51	1.43	1.19	0.92	1.49
	o6	1 163			0.74			1.19		
	o9	1 027	563	1 198	1.01	0.74	1.62	1.10	0.91	1.24
	o10	844			1.48			0.91		
	o11	18 690			0.03			1.97		
	o12	1 220			0.75			1.13		
	o13	663			1.67			1.03		
	w1	118			1.28			0.39		
	w2	858			0.07			0.95		
	w3	140			1.02			0.41		

Results from ASPIC runs show a rather inconsistent pattern in biomass and fishing mortality benchmarks as depicted in Figure 49. Many of the biomass ratios are near to or over 1.0. Fishing mortality ratio estimates range from near unfished (near 0.0) to completely overfished (exceeding 3.0). The equivocal nature of the results given different model assumptions were cause for concern by the assessment group and most likely attributed to either failure of the data to have agreement in trends or lack of contrast in abundance throughout time. The assessment group also noted that ASPIC had slightly more difficulty fitting to combined indices in the western Atlantic. In ASPIC runs that implemented bootstrapping, maximum sustainable yields ranged from about 1 000 tonnes to 1 500 tonnes at 50 percent confidence intervals. ASPIC runs that used lengthy indices and had a long time series of biomass and mortality benchmark estimates were used to show the phase trajectory of the sailfish stock from 1958 to 2007 (Figure 50). According to the phase plot in Figure 50, the sailfish stock has transitioned from an underutilized stock to one that is approaching an overfishing condition. Results in the ASPIC approach may be considered preliminary until more comprehensive data can be integrated in an assessment and results could be more of an artifact of model-fitting than of stock signals. Nevertheless, the western Atlantic stock has declined since the 1960s, though the stock has been stable since the 1980's. Although no projections were made with respect to future catches, the assessment group recommended that western stock catches not exceed most recent reported catch.

FIGURE 49

**Kobe plot of  $F/F_{MSY}$  and  $B/B_{MSY}$  ratios for sailfish in the western stock as estimated by numerous ASPIC runs**

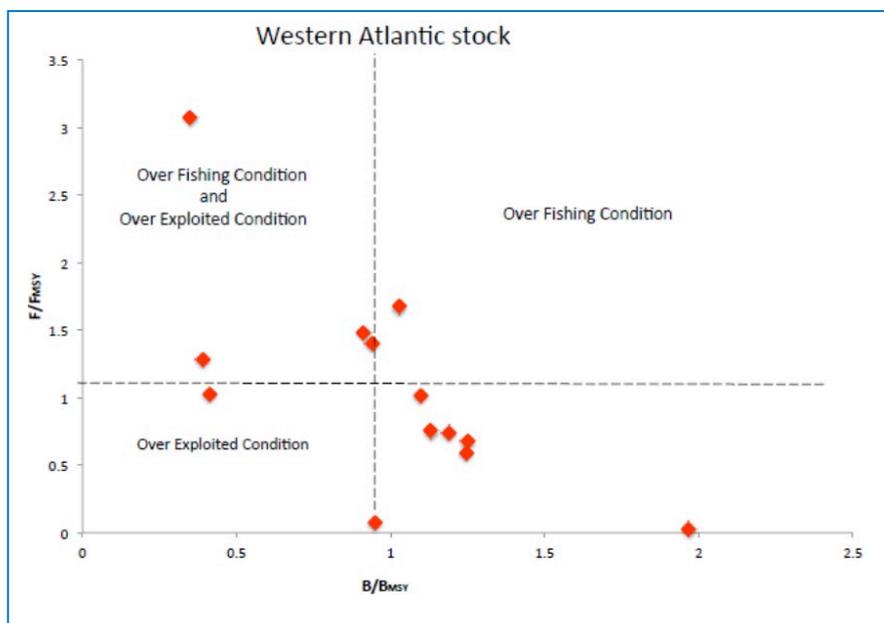
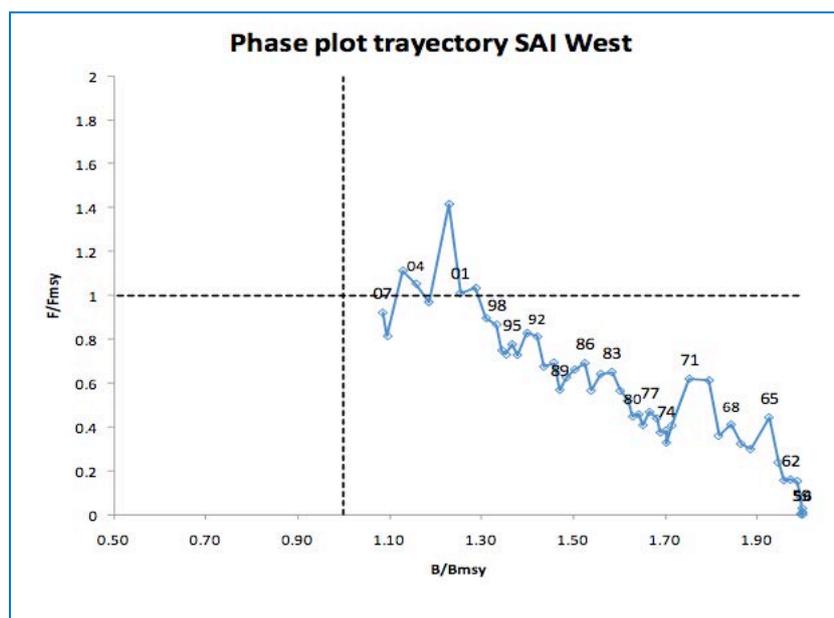


FIGURE 50

**Phase plot of  $F/F_{MSY}$  and  $B/B_{MSY}$  ratios for sailfish in the western stock throughout time in a comprehensive ASPIC run from the late 1950s to 2007**



## 4.2 WECAFC stock scenarios

Billfish stock assessments carried out by ICCAT for units of stock in the north and northwest Atlantic are of interest to the status of billfish availability in the WECAFC region. The assessments used the best biological and fisheries statistics available and the best scientific knowledge useable for the purpose of the stock assessment models used. The assessments concluded that observed billfish data deficiencies are a hurdle to the stock assessment process and that in some cases the information base was not sufficient to the point that status of exploitation depended more on the convergence of the

models to different data sources than truly representing a trend in stock abundance (e.g. western Atlantic sailfish). Precision of exploitation estimates is generally low and significantly depended on assumptions made about the objectively collected data for billfish stock assessment purposes. Consequently, stock exploitation bench marks such as  $F_{\text{estimated}}/F_{\text{MSY}}$  or  $B_{\text{estimated}}/B_{\text{MSY}}$ , could not definitely or at least unambiguously ascertain if billfish stocks were over exploited, over fishing or both. Despite data issues, lack of model convergence, and difficulties in the interpretation of the results, there is a clear indication from the stock assessment results that billfish stocks in the north and northwest Atlantic have significantly been impacted by fisheries targeting tunas where billfish are caught incidentally since the 1950's. The WECAFC region covers only a fraction of the ICCAT Convention Area (Figure 2) and it is of interest to review the trends and signals that could indicate how important is the unit of stock exploitation condition reflected in the fractions of the units of billfish stocks observed in the WECAFC region. Such understanding is of paramount importance to the WECAFC mission to properly manage billfish stocks.

Since billfish resources within the WECAFC region are only a fraction of the units of stocks in the Atlantic, it is not possible to consider formal stock assessments pertaining to those fractions. However, it is possible to draw some conclusions by analyzing indices of local relative abundance (CPUE) derived from local fishery statistics as well as compare the signals in relative stock abundance with biological signals that are concomitant or resulting from the effects of exploitation in the region. Such approach will allow a better dimensioning of the best regulations that could result in the best economic and social use of the billfish resources that are significant among the highly migratory species group in the WECAFC region.

Historic blue marlin records of relative abundance may be drawn for Venezuelan sport fishing records for the period 1960 until this important sport fishery ceased in 1996, and CPUE data from the Venezuelan gillnet fishery in the eastern Caribbean (Figure 51 upper figure). The two relative abundance indices have different scales as expected but they appear to match signals given that gillnet CPUE follows similar signals at different scales with the US recreational CPUE (Figure 51 lower figure) and the US recreational CPUE overlaps with the Venezuelan sport CPUE for the period 1978–1996 (Figure 52 upper figure). The standardized (observation minus mean divided standard deviation) data for all CPUE data from the WECAFC region is shown in Figure 52 lower figure. Blue marlin relative abundance follows large fluctuations with significant depletions during 1970–1980, then from 1984–1992 and finally a low relative abundance level after 2000 (Figure 52 lower figure). The observed trends in the different CPUE series may be corroborated in part when comparing the relative abundance of blue marlin expressed by the CPUE of the Venezuelan gillnet fishery and the trophy size of blue marlin reported to IGFA (Figure 53). In general it is observed that blue marlin resources in the WECAFC area decreased significantly after 2000 relative to the fluctuations in relative abundance in periods prior to that year. It is not known if this may be an effect of the increased fishing intensity exerted on pelagic resources in the eastern Caribbean Sea, especially after the introduction of mFADs in the second half of the 1990s.

FIGURE 51

Historic distribution of blue marlin relative abundance in the Venezuelan sport and gillnet fisheries (Upper figure); and a comparison of relative abundance signals between the Venezuelan gillnet and the US recreational fisheries (Lower figure) where a 2-year moving average was fitted for better interpretation of the signals

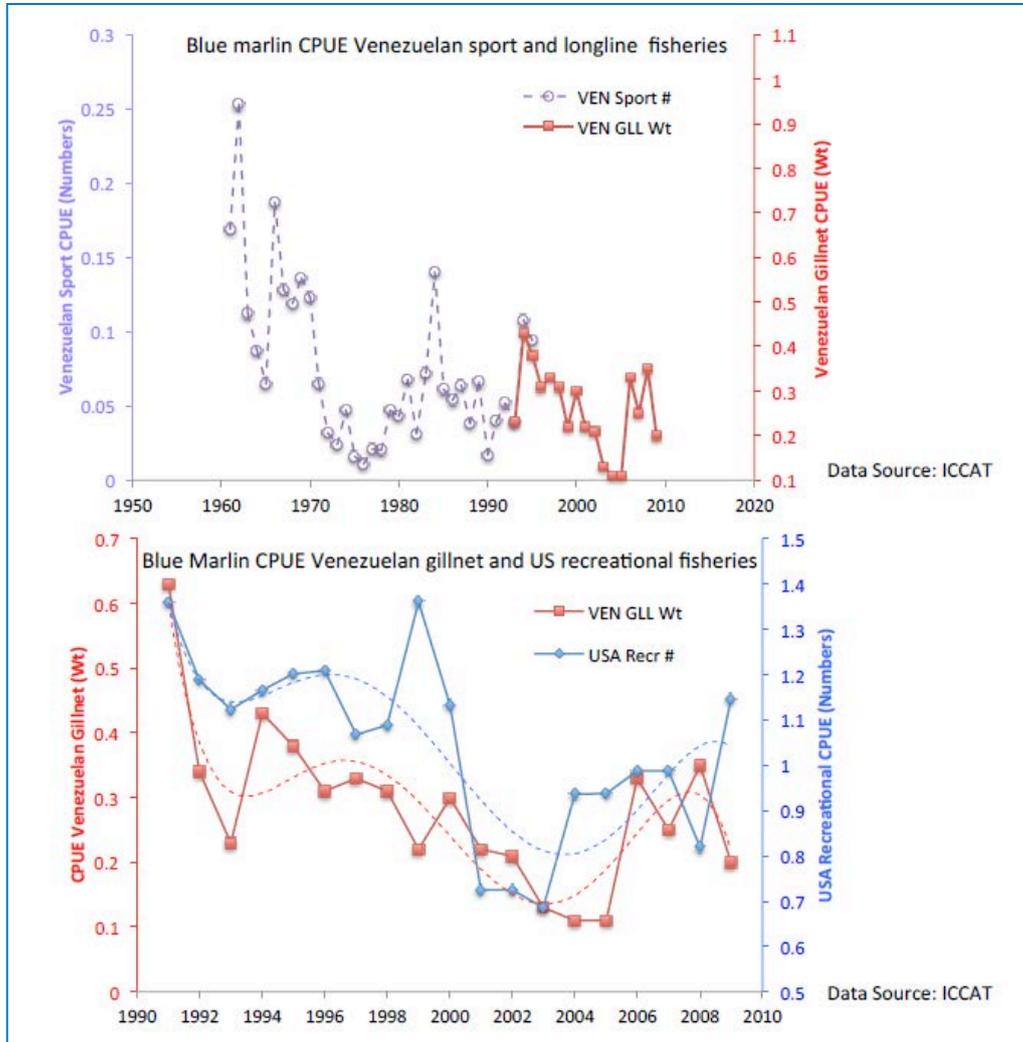


FIGURE 52

Blue marlin relative abundance trends from Venezuelan and US sport fisheries data (Upper figure) and standardized relative abundance for all fisheries data available for blue marlin in the WECAFC area

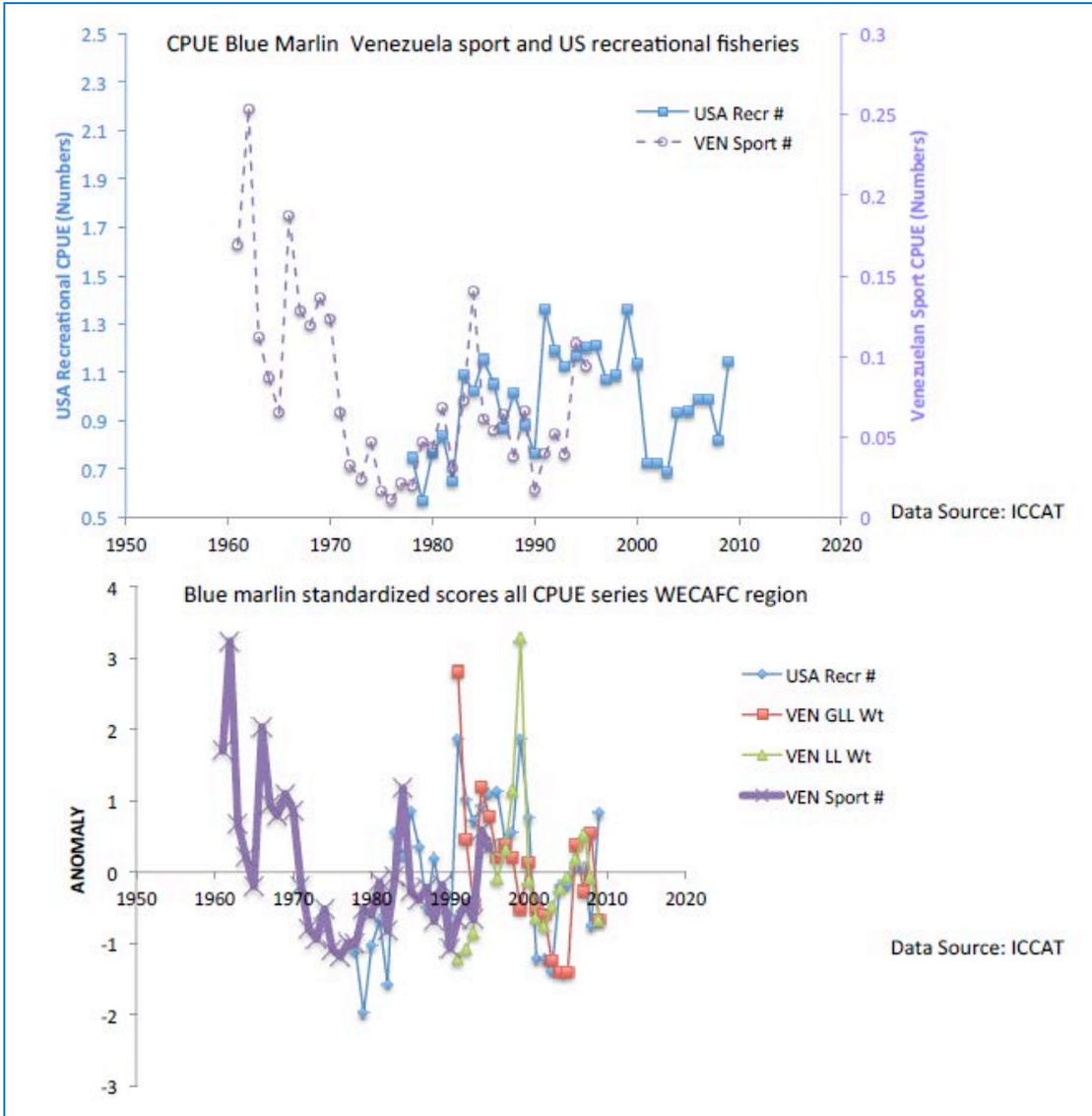
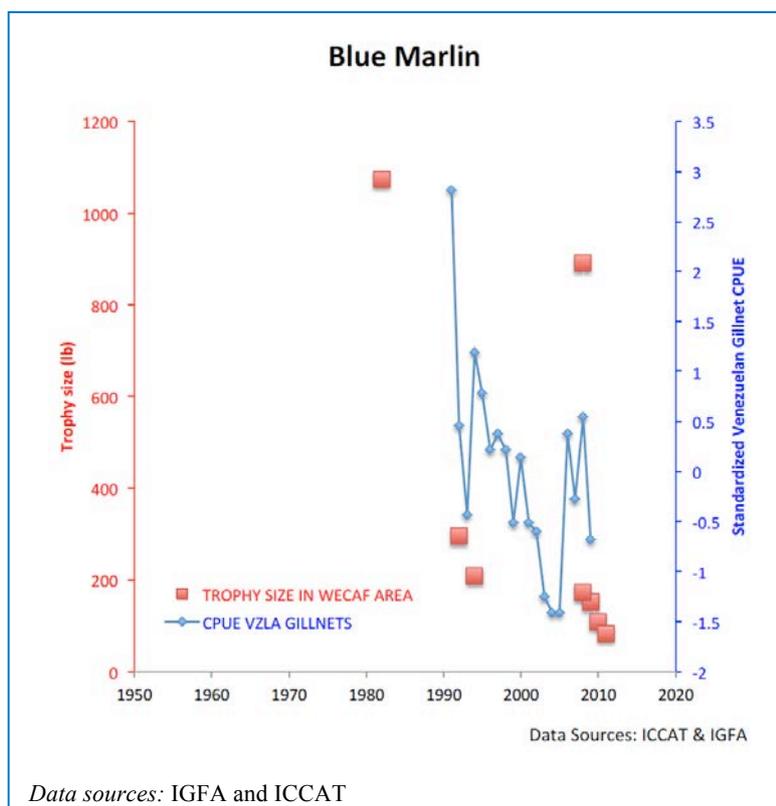


FIGURE 53

**Blue marlin trophy sizes and relative abundance index**

White marlin has been subjected to intensive fishing within the WECAFC region and in the central equatorial Atlantic and relative abundance data (CPUE) from the WECAFC region is available only for the sport fishery in Venezuela that lasted until 1996 and for the US recreational fisheries for the period 1973–2011 (Figure 54). The decreasing CPUE trend in the Venezuelan fishery is significantly more impacting than the CPUE in the US fishery. It is not know if such difference may be due to the localized intense gillnetting and longlining by Venezuelan fleets (Figure 17). From the figure it may be concluded that White marlin in the WECAF region does not show fluctuation in relative abundance similar to those observed with blue marlin. Contrarily, it shows a steady low relative abundance level that may not be recoverable with localized regulations. These CPUE trends also depict a very noticeable match with drops in white marlin trophy size (Figure 55)

FIGURE 54

White marlin relative abundance (CPUE) trends for the sport fisheries in Venezuela and the US

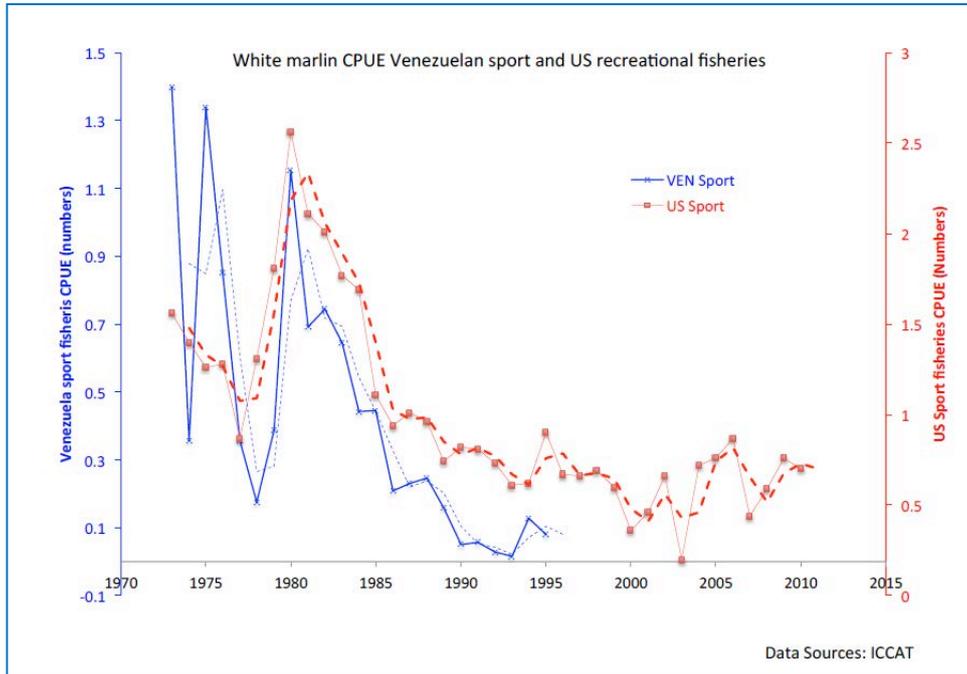
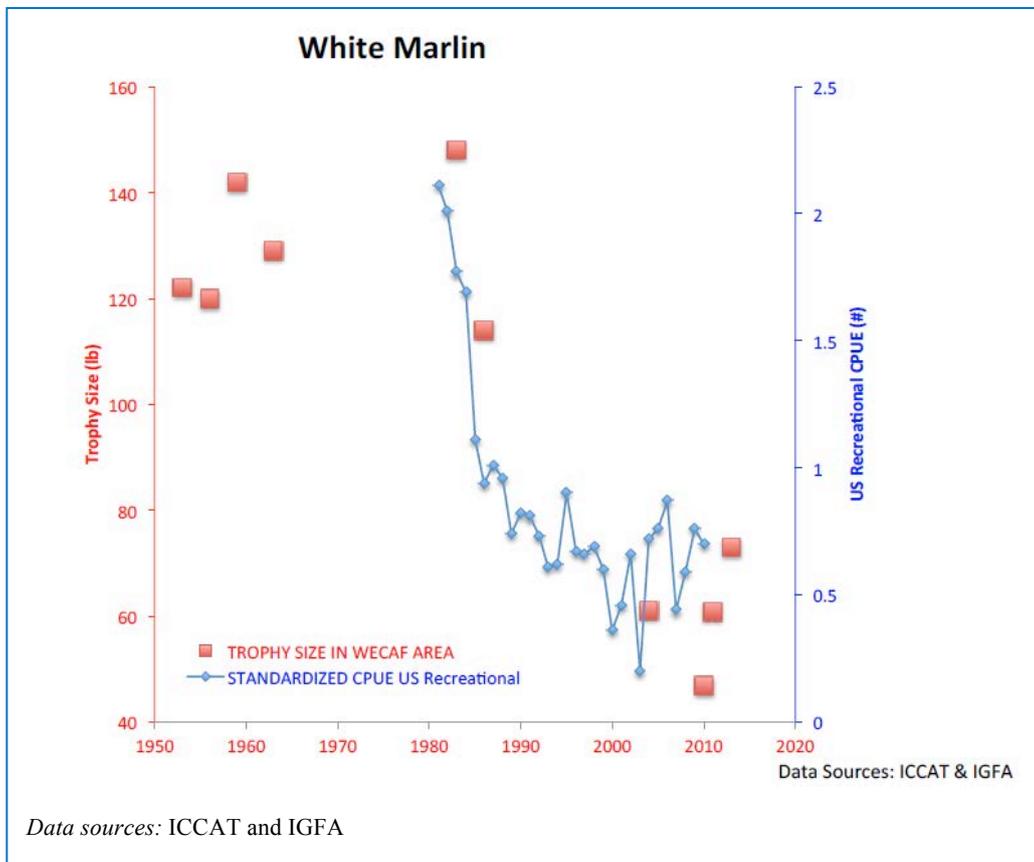


FIGURE 55

White marlin trends in relative abundance in the US recreational fisheries and trophy sizes



Data sources: ICCAT and IGFA

In the most recent white marlin stock assessment (ICCAT, 2012), data on the decreasing number of individuals larger than 200 cm LJFL in the biological statistics organized by ICCAT by decades (Figure 8 in the stock assessment report). We reconstructed the age length key for each of the decades using growth parameters for white marlin given by Laretta and Brown (2012) and used a new algorithm that uses growth variance-covariance to fit an objective function that compares observed with expected length frequencies using an input change in initial stock abundance and recruitment (Fitchett, 2015; Fitchett and Ehrhardt, 2016, submitted). Output from such algorithm are frequencies of age at size and with those statistics we proceeded to estimate total mortality rates ( $Z$ ) for each accumulated decadal size percentages over 200 cm LJFL. We adopted a natural mortality rate of 0.20 to estimate an average decadal fishing mortality rate ( $F$ ). These mortalities are compared in Figure 56 with the percent disappearance of size frequencies at age by decades reported by ICCAT. Two aspects are important to note: 1) the negative correlation of the input data on size frequencies by decades and the increasing values of fishing mortality, and 2) the fishing mortality in the last decade of data available (i.e. 2000s) is approximately 3.7 times as high as the fishing mortality reference point offered by the ICCAT stock assessment that will generate maximum sustainable yield for the species. To corroborate the resulting  $F$ -estimates by decades, we summarized the decadal overall longline fishing effort in the Atlantic. The comparison is given in Figure 57, where there is a clear positive correlation between the two estimates. This is an indication that in fact the disappearance of the larger individuals in the white marlin biological samples are the result of a significant increase in fishing mortality exerted on this unit of stock.

FIGURE 56

**Trends in decreasing number of individual white marlin larger than 200 cm LJFL and the fishing resulting mortality rate that any have generate such effect**

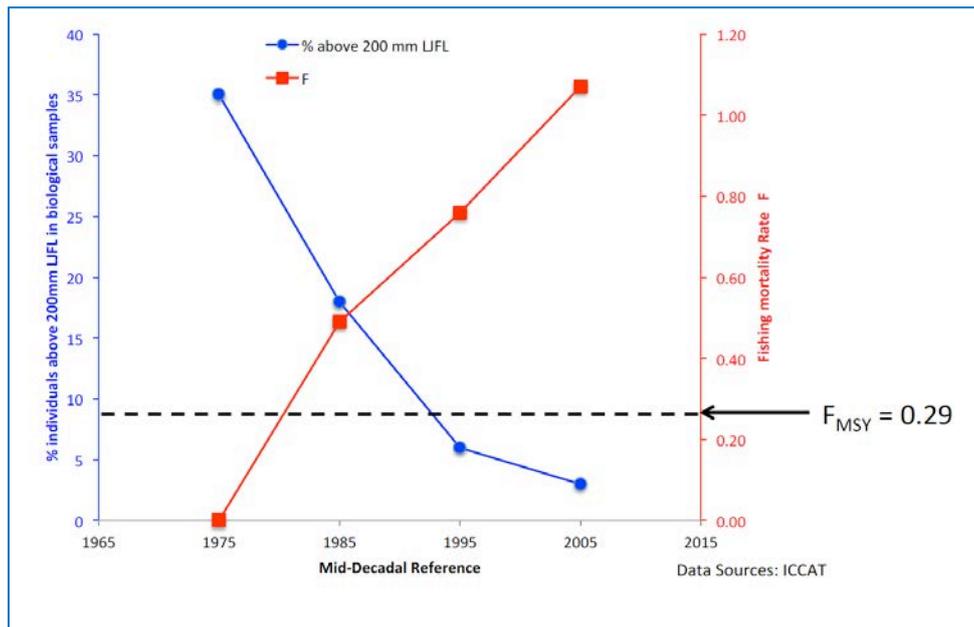
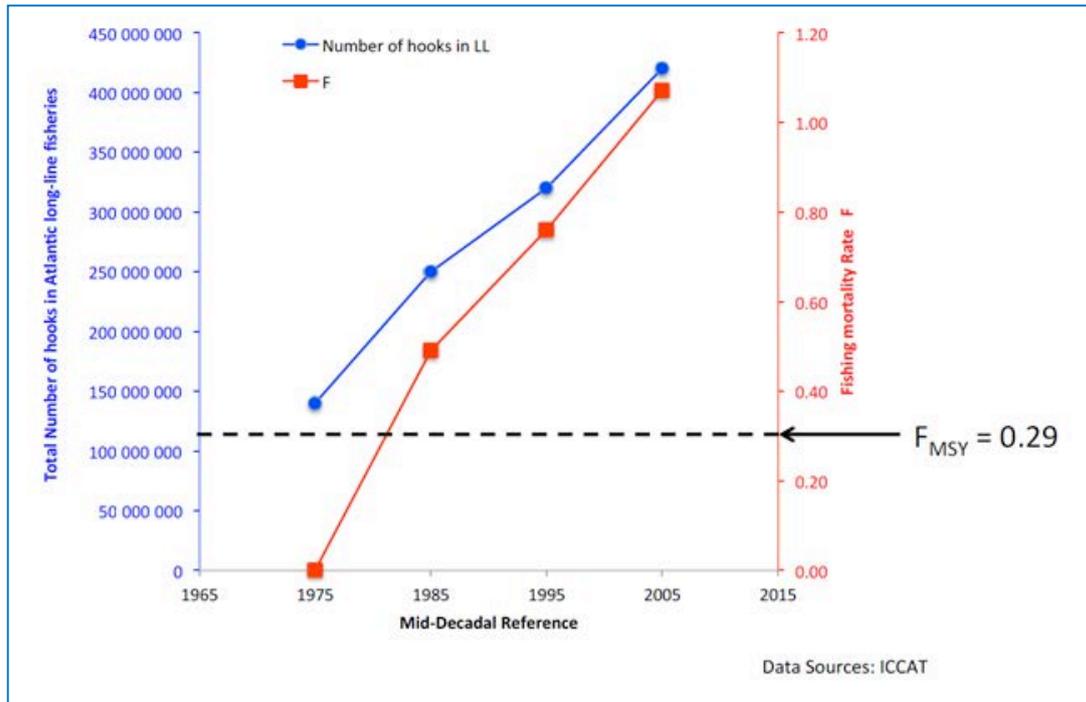


FIGURE 57

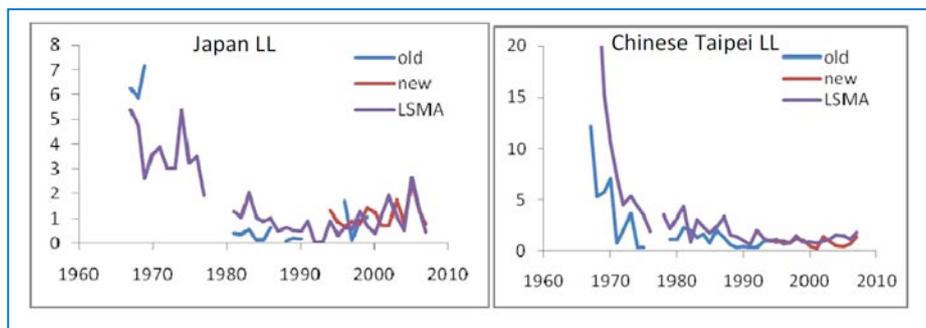
**Total number of hooks fished by all fleets by decades in the Atlantic and white marlin fishing mortality rates estimated from the effect of disappearing size frequencies larger than 200 cm LJFL in biological samples**



For the case of sailfish, there is no data to carry out similar analyses in the WECAFC region. Sailfish stock assessments have been significantly impacted by the lack of information on landings and biological samples from the coastal fisheries that impact this species more significantly. However, the relative abundance data from the large industrial longliners from Japan and Chinese Taipei offer historic CPUE trends of the species in the north Atlantic (Figure 58). In those figures prepared by the 2009 ICCAT sailfish stock assessment it is evident that the stock has been significantly depleted after the 1980s.

FIGURE 58

**Sailfish relative abundance (CPUE) trends prepared by the ICCAT stock assessment. (N.A: No CPUE units are offered in the original report)**



## 5. CONCLUSIONS

It is observed that main constraints in the ICCAT stock assessment processes for Atlantic billfishes have been differences in signals provided by the various CPUE series together with data insufficiency on landings and on growth. The CPUE statistical problem originates from fishing power differences among fleets, regions, and seasons as billfish stocks migrate seasonally and fishing intensity (fishing effort per unit of area) changes according with the seasonal availability of targeted tuna species and not the billfish. Thus, tuna fishing intensity may be decoupled from billfish spatial-temporal population dynamics, which is not properly documented. In addition, the incidental (by-catch) nature of the billfish in tuna fisheries further complicates the implementation of more refined billfish data collection aboard vessels. Catches obtained with the use of both drifting and moored FADs also mar considerably the efforts to quantify CPUE as a proper index expressing signals of relative billfish stock abundance status. This is mostly due to the nature of FADs that accumulate biomass independently of the status of abundance of the stock, but of a local density effect until population abundance become a rare condition that may result in sudden stock collapse. In those situations, CPUE indices define hyperstability conditions and represent a major hurdle to standardize fishing effort in the Atlantic tuna and billfish fisheries using FADs. ICCAT is concerned with the difficulties in assessing tuna stocks (and by consequence billfish stocks) due to the lack of more detailed information on the nature of FAD fishing. A FAD working group was recommended at the 24<sup>th</sup> Regular Meeting of the Commission held in Malta in November 2015 with the purpose of researching the effects of FADs on tuna fishing. The adoption of mFADs in the WECAFC region has also created major issues regarding: 1) data gathering that are not objectively collected for stock assessment purposes, 2) ill-conceived and unregulated property rights on mFAD deployment, and 3) competition between commercial mFAD owners and sport fishers. At present, recreationally caught and destined to be released blue marlin in the eastern and central Caribbean, are retained by commercial fishers operating mFADs. This practice of surrendering the recreationally caught billfish to commercial fishers contravenes the 7th recommendation of 24<sup>th</sup> ICATT Regular Meeting regarding the prohibition of selling recreationally caught marlin.

Several major efforts and investments to improve the billfish stock assessment database have been done by ICCAT. There are main research concerns related to stock structures and movements, discerning growth and sexual dimorphism characterizations in landings, and better estimates of natural mortality. Billfish stock assessment results are indicative of significantly decreasing trends in abundance of the three main billfish species considered in this study: blue marlin, white marlin and sailfish. According to the most recent stock assessments for each of the billfish stocks in the Atlantic, the exploitation status criteria resulted in different conditions depending on important differences in the data included in the models fitted and the assumptions adopted for each run. Based on the two exploitation reference indices,  $F/F_{MSY}$  and  $B/B_{MSY}$ , blue and white marlin are over exploited and undergoing over fishing while sailfish was declared as undergoing over exploitation and likely over fishing. However, the sailfish stock assessment data was insufficient regarding landing data and more appropriate CPUE indices from artisanal fisheries in the coastal regions of the western Atlantic stock. Stock assessment results can be summarized in Table 9.

Table 9

**Fishery status benchmarks,  $F/F_{MSY}$  and  $B/B_{MSY}$ , for blue marlin, white marlin, and sailfish in most recent ICCAT assessments for the species**

	$F/F_{MSY}$	$B/B_{MSY}$
Blue Marlin (ASPIC High Productivity)	1.330	0.57
Blue Marlin (Fully integrated model)	1.633	0.67
White Marlin ASPIC Reported catch	0.99	0.50
White Marlin ASPIC Catch Upper	3.24	0.49
White Marlin ASPIC Catch Middle	1.79	0.50
White Marlin Statistically Integrated (SS)	0.72	0.32
Sailfish (Comingled with Spearfish)	0.95	1.08

Trends in recruitment for white marlin show steady declines over five decades of existing data, reaching 28 percent of nascent recruitment levels estimated for the 1960s by the 2000s. Analyses carried out by this project indicate that white marlin fishing mortality rates (F) have steadily increased by decade from an F less than 0.01 in the 1970s, 0.49 in the 1980s, 0.76 in the 1990s to an F greater than 1.07 in the 2000s. Decadal fishing mortality rates are well correlated to the trends in total long-line fishing effort reported for those decades in the Atlantic. Fishing mortality rates in the 2000s is 5.4 times higher than the natural mortality (M) adopted in the billfish stock assessments ( $M=0.2$ ) and 3.7 times as large as the fishing mortality reference point that would generate maximum sustainable yield of the species. This is a clear indication that white marlin is still being subjected to a very high exploitation rate.

Regional CPUE as an index of relative abundance for blue marlin and white marlin in the WECAFC region was obtained from data in recreational fisheries in the USA and Venezuela as well as commercial operations by Venezuelan gillnet and long-line fleets. The analyses show that relative indices of abundance reflect common signals of stock depletions. In fact, blue marlin CPUE decreased 68 percent from a relative abundance level since the early 1990s, while white marlin relative abundance decreased 72.7 percent since 1980. Our analyses further indicate strong correlated signals of decreasing CPUE trends with decreasing ‘trophy size’ of white and blue marlin in recreational fisheries, where declines of trophy size, independent of recreational fishing gear specification provided by IGFA, are 60.4 percent and 92.4 percent, for the two species, respectively. No information of this type was available for sailfish.

Several billfish regulations are implemented in recreational fisheries of the US, Puerto Rico, and the US Virgin Islands. Attempts to manage the billfish resources by ICCAT are framed by knowledge on potential annual quotas and status of exploitation. In the late 1990s, ICCAT established the regulation that requires that vessels discard by-catch of live billfish in the industrial fisheries. However, there are no comprehensive research results available regarding the survivorship of those animals discarded alive. There is no known information available in the literature about billfish handling once aboard large industrial longliners or purse seiners. Presumably, most of the discarded billfish is dumped back to the sea after an unknown time on deck. There is anecdotal evidence in the literature that billfish may be used as bait in some longline fisheries, but firm official statistical evidence does not exist to corroborate these processes that significantly affect regulations established by ICCAT. On the other hand, ICCAT has reported that increases in billfish relative abundance during the 2000s may be an effect of the billfish release regulation. This opinion is challenged in other reports indicating that increases in landings of tuna and tuna-like species since the late 1990s may be due to the significant

implementation of drifting and moored FADs as attractants in the pelagic fisheries, and especially in those of the eastern Caribbean Sea. Billfish parental stock and recruitment abundances also are following strong and consistent negative decreasing patterns. Finally, there are concerns that the observed decreases in billfish landings from the larger industrial long-line fisheries, which are argued to be a result of changes in fishing tactics due to regulation, may be in fact what other reports indicate: that such fleets are not properly reporting all billfish discards as regulated by ICCAT. Therefore, in the ICCAT billfish stock assessments, it has become necessary in some instances to assume that reported billfish landings (e.g. white marlin after 1997) are the minimal expected landings and middle and/or maximal expected (assumed) catch levels were assigned to portray the possibilities of non-reporting of discard events after implementation of the billfish discard regulation.

The desk review could not find any viable regulation that would revert the status of exploitation of billfish species in the Atlantic given the mostly minimal bycatch nature of the billfish landings in industrial tuna fisheries. However, the economic and social value of the species for the recreational fisheries in the WECAFC region may merit stricter regulation in the regional hook and line fisheries targeting pelagic species. Under such billfish conservation frame, it may be possible to enhance localized billfish recreational catch rates. By achieving this desirable outcome, recreational fisheries will continue to provide employment and economic benefits to many island countries in the Caribbean region. The use of circle hooks in recreational billfish fisheries can reduce deep hooking (Prince *et al.*, 2002). Therefore, the wide-spread use of circle hooks in recreational fisheries increase the post-release survival of billfish in many fisheries while not negatively affecting catch rates of target species (Musyl *et al.*, 2015). In fact, most billfish recreational fisheries are catch and release and circle hooks are the standard to make such practice successful and practical. Scientists have determined that circle hook usage as a pragmatic gear modification in longline fisheries have profound impacts on fishing mortality and induces substantial changes to marine trophic dynamics (Kitchell *et al.*, 2006). The 24<sup>th</sup> ICCAT Regular Meeting held in Malta on 10–17 November 2015, following recommendations of the SCRS, recommended that the Commission consider making circle hooks compulsory in fisheries that may catch billfish and other non-target species of concern to reduce incidental mortality. However, the Commission did not approve such recommendation. The use of circle hooks in highly migratory pelagic fisheries in the eastern Caribbean Sea and those associate with mFADs can contribute significantly to the survivorship of released billfish from commercial hook and line gear, if such practice is adopted.

Lastly, Regulations are urgently needed to avoid further confrontation between commercial mFAD fishers and recreational billfish fishers in the region. The perception of proprietary domain over mFADs and the resources in their proximity has already lead to contentious behaviors between recreational and commercial fishers, including commandeering of recreationally-hooked billfish by commercial fishers while recreational vessels are fishing.

## 6. RECOMMENDATIONS

Although this desk review was not designed to generate recommendations, the findings lead to generate a frame of potential studies that could improve significantly the billfish conservation efforts in the WECAFC region. A succinct description of the most significant recommendations follows:

1. To carry out a major review and re-assessment of billfish growth to define more appropriate growth models to be incorporated in the billfish stock assessment works by ICCAT.
2. To design and implement a realistic and effective pilot program on recreational fishery statistics in the WECAFC region such that regional regulations may be better designed. The purpose of using recreational fisheries is due to the historic databases available for these fisheries and the need to consistently recover information that is objectively collected in these well-established fisheries. This recommendation does not include development on artisanal fisheries based on the difficulties that the FAO has reported on artisanal data collection systems in the eastern Caribbean.
3. To develop validated regional indices of billfish relative abundance that could be incorporated in ICCAT's stock assessment works.
4. To develop a WECAFC integrated analyses of the ecological and fishery effects of mFADs due to the fact that most mFAD supported fisheries in the region show consistently high catches of billfish, more conspicuously of blue marlin.
5. To study the habitat use by the billfish resources in the WECAFC region by means of satellite tagging programs. This work will facilitate resource allocations, definition of potential protected areas and seasonal fishing regulations, and enhancing fishing practices between fishing sectors.

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***Section on Conclusions***

**Kitchell, J.F., Martell, S.J.D., Walters, C.J., Jensen, O.P., Kaplan, I.C., Watters, J., Essington, T.E. and Boggs, C.H.** 2006. Billfishes in an ecosystem context. *Bull Mar. Sci*, 79, 669–682.

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This circular provides a review of the status of billfish resources and fisheries in the WECAFC region. It considered over 100 documents on the subject matters. Billfish are generally caught as bycatch in Atlantic tuna fisheries. They represent a mere 0.76 percent of the tuna landings and this characteristic represents a major hurdle to objectively collect statistical data for billfish stock assessments. The review found that billfish resources have been subject to intense exploitation in the tuna and tuna like fisheries in the Atlantic Ocean for more than six decades, and as a consequence billfish resources appear depleted, overfished and/or undergoing overfishing. The area of the WECAFC is critically important to the habitat domain of the billfish in the western Atlantic.



ISBN 978-92-5-109436-5 ISSN 2070-6065



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I6204E/1/09.16