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ON THE SEASONAL DYNAMIC CHARACTERISTICS OF THE SAILFISH, *ISTIOPHORUS PLATYPTERUS*, IN THE EASTERN PACIFIC OFF CENTRAL AMERICA

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ABSTRACT

The greatest catch rates in the world for sailfish [*Istiophorus platypterus* (Shaw in Shaw and Nodder, 1792)] occur in an area of the Eastern Pacific Ocean off Central America, where this species supports multi-million dollar catch-and-release sport fisheries associated with tourism in Costa Rica, Panama, and Guatemala. Sailfish is also caught as by-catch in expanding coastal artisanal long-line fisheries, which primarily target mahi-mahi, sharks, and tunas. Furthermore, sailfish have been historically impacted as by-catch in the very large industrial high seas long-line tuna fisheries since about 1964. In spite of the importance of sailfish to the Central American fisheries and their local economies, very little is known about its population dynamics and status of exploitation. We present an ecosystem view of likely mechanisms regulating the seasonal relative abundance of sailfish off Guatemala. Overall, regional sailfish abundance is 80% below their initial 1964 levels and trophy sizes of recreationally caught sailfish have declined at least 35% from their unexploited trophy sizes. These developments compromise the strategic value of the resource to the sport fishing industries and generate conflicts among stakeholders. We postulate the need for a regional fishery management plan for the sailfish as a way to promote sustainable use of the resource.

Sailfish [*Istiophorus platypterus* (Shaw in Shaw and Nodder, 1792)], is widely distributed in the Pacific Ocean (Nakamura, 1985), and is primarily subjected to incidental exploitation in the high seas and coastal longline fisheries. It is also an important resource targeted by sport fisheries. It is unclear whether a single or several stocks describe the sailfish population composition in the Pacific and their regional or global abundance is unknown. However, it is well established that the eastern Pacific Ocean (EPO), particularly off Central America, is one of the areas that has historically generated the highest catch rates in the industrial longline (Miyabe and Bayliff, 1987, fig. 18) and sport fishing industries (Fig. 1).

In Central America, billfish are vital to a promising new multi-million dollar sport fishing industry that represents a unique opportunity for regional economic and social development. This development is taking place through the tourism sector where conservation plays a major role. In this regard, the billfish sport fisheries in Central America are mostly catch-and-release fisheries aimed at securing the long range sustainability of these highly exploited resources.

Since the mid-1990s, demand for mahi-mahi, (*Coryphaena hippurus* Linnaeus, 1758) and fresh tuna has increased dramatically in the international markets (mostly the U.S.A.). As a consequence, local artisanal fisheries in Central America, primarily in Costa Rica, Nicaragua, Guatemala, and Panama, responded to the increased demand by developing longline fisheries in the coastal and high seas regions of the EPO off Central America. The fishing capacity of these artisanal and semi-industrial fleets has grown considerably without control by local governments. Mahi-mahi landings in Costa Rica declined at an average rate of 300 t per year during 2001–2004 and the Nicaraguan fishery followed a similar declining trend, such that in 2004

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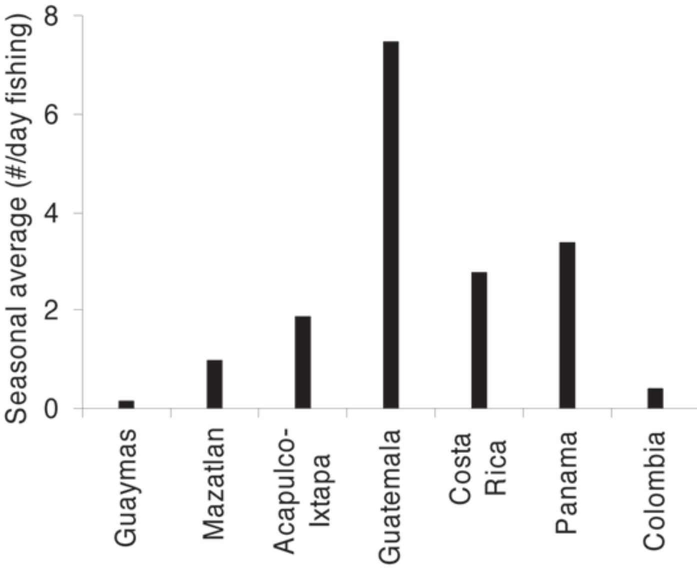


Figure 1. Regional distribution of the average number of sailfish (*Istiophorus platypterus*) caught per day fishing in the sport fisheries in 2000–2002.

it totaled only about 50% of the landings reported in 2000. These declining trends may be due to the fishing overcapacity of the fleets. As a result, fishers now claim the need to make better use of the incidental catch. Sailfish, as one of the important incidental species caught in these fisheries, is subjected to an unknown, but assumed high, level of fishing mortality throughout the Pacific. Panama, Nicaragua, and Guatemala have laws that specifically protect sailfish from being landed in commercial fisheries. Costa Rica also had such legislation, but it was modified in 2005 to allow the landing of billfish. Enforcement of management policies pertaining to billfish in Central America is usually lacking and it is common to observe billfish offered in local markets. This scenario is a source of concern to the tourism-supported billfish sport fishing industry.

At present, the artisanal and industrial longline fishing fleets have conflicting interests with the sport fishing fleets regarding use of the billfish resources. Therefore, establishing precautionary billfish fishing practices and controlling exploitation to promote sustainable use of this resource in Central America are urgent needs.

In this paper, we present an integrated view of some of the biophysical characteristics that frame the exploitable dynamics of the sailfish populations in the EPO off Central America. The aim is to set up the basis for the development of a regional billfish/sailfish fishery management strategy that could result in less conflict among stakeholders and better use of the valuable, but declining sailfish resources in the region.

Sailfish Distribution and Habitat Characteristics

Sailfish, although widely distributed throughout the Pacific between 35°N and 25°S shows regional concentrations that differ significantly from the distribution of other billfish species. Joseph et al. (1974, fig 12) show the results of a comparative

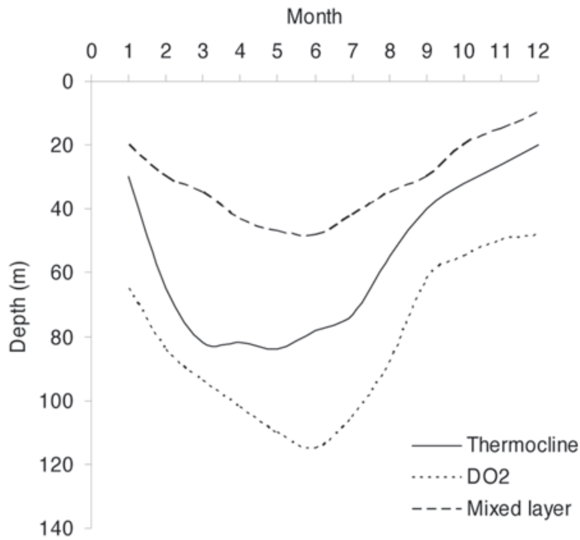


Figure 2. Seasonal variability of the thermocline, mixed layer and minimum (1 ml L^{-1}) of dissolved oxygen (DO_2) off the coast of Guatemala (adapted from NORAD/UNDP/FAO 1988).

analysis of the sailfish and shortbill spearfish, (*Tetrapturus angustirostris* Tanaka, 1915), caught in exploratory longline fishing surveys in the EPO in the 1950s and 1960s in an era prior to the advent of the large industrial longline operations. They found that sailfish comprised nearly 100% of the relative catch in an area shoreward of a line drawn from the intersection of 10°N and 115°W to the intersection of 5°S and the coast of Peru, while showing a significant drop in catch rates in the oceanic areas beyond about 1600 km from the coastline. This spatial demarcation broadly includes the EPO off Central America and it has been used to define sailfish as the most landmass-associated of the billfish species found in the region. Within this area sailfish appear to conduct extensive migrations in an apparent northerly direction with the displacement of warm water to the north during the summer and fall (Joseph et al., 1974). These migrations are mostly along the coast of Central America, generally occupying the upper 100 m of the water column (P. Rice et al., University of Miami, unpubl. data) with marked residence preferences above the 25 m isobath, and within water temperatures ranging from 14 to 32 °C, but mostly between 28 and 30 °C (Prince et al., 2006).

In the EPO off Central America, the sailfish distribution in the pelagic habitat appears severely constrained by the persistence of low Dissolved Oxygen (DO_2) levels close to the surface (NOAA World Ocean Atlas website). For example, off the coast of Guatemala—an area with the highest regional sailfish catch rates (Fig. 1)—the minimum DO_2 level of 1 ml L^{-1} is found varying seasonally between 50–115 m while the seasonal depth of the mixed layer varies between 10–50 m and the seasonal thermocline depth between 20–85 m (NORAD/FAO/UNDP, 1988; Fig. 2). Seasonal depth of these environmental variables are related to conspicuous seasonal changes in mean sea level (MSL), e.g., as registered in the Acajutla, El Salvador Sea Level Station (Kilonsky, 2005), and upwelling intensity due to the seasonal wind regimes that prevail, e.g., over Nicaragua (INETER, 2005; Fig. 3). The intensity of the northeasterly Caribbean winds passing through the Great Lake of Nicaragua district and the Gulf of

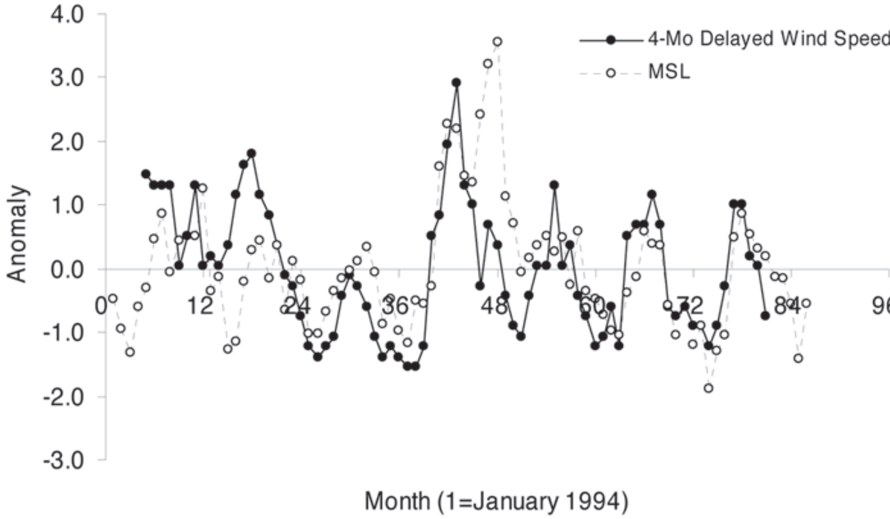


Figure 3. Seasonal anomaly of the Mean Sea Level (MSL) of Acajutla, El Salvador, and the 4-mo delayed effect of the northeasterly winds passing through the Papagayo jet.

Papagayo during the dry season (November–April) has a 4 mo delayed effect on the MSL in Figure 3. Similar wind jets also pass through low elevation gaps in southeastern Mexico, the Tehauntepec jet originates from seasonal cold fronts moving southward in the Bay of Campeche (Gulf of Mexico) (Stumpf, 1975; Bourassa et al., 1999). Likewise, the Panama jet originates from seasonal north-easterly winds from the Caribbean passing through the Panama Canal Zone and the Gulf of Panama (Chelton et al., 2000). Thus, from November to April, the prevailing winds create intense cooling by upwelling of nutrient rich waters from the deep in the areas immediate to the passages and extending to approximately 160 km offshore (Wyrki, 1964; Stumpf, 1975). During these months, surfacing of the mixed layer, thermocline, and minimum DO_2 levels is significant (Fig. 2). In addition, linkages between the Northern Equatorial Countercurrent (NECC) and the Costa Rican Coastal Current (CRCC) deteriorate during this time period due to the advection of surface water and eddy formation (Fiedler, 2002). In the region off Guatemala, both cyclonic and anticylonic eddies have been observed to form as a result of the Tehuantepec and Papagayo jets from late fall through winter and then dissipate with the strengthening of the NECC (Willet, 1996) and the deepening thermocline, mixed layer, and minimum oxygen level. Sea Surface Temperature (SST) data and satellite imagery from SeaWIFS/AVHRR (1997–2000) and MODIS (2000–2005) show formation of conspicuous seasonal meandering eddies under winter conditions and the absence of such formations under summer conditions (Fig. 4). These eddies most likely represent a significant seasonal biophysical feature to sailfish as they may act as retention mechanisms for planktonic organisms as well as eggs and larvae, which are sources of food for first-order consumers and planktivorous fishes. During this time, sailfish show the highest population density (see below) off Central America while during months of relaxed wind activity (May–October) the CRCC gets re-established northbound along the coast of Central America (Bakun et al., 1999) when biological productivity along the immediate shore is the lowest and the sailfish density also decreases.

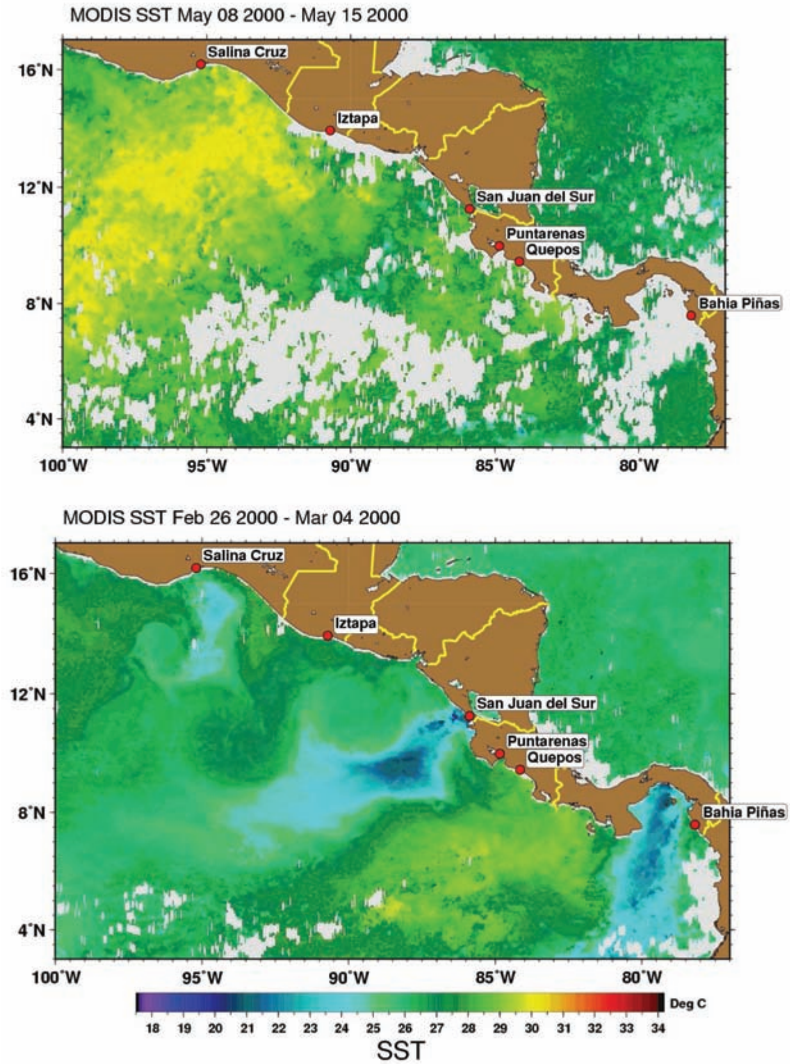


Figure 4. Seasonal oceanographic features resulting from wind passage through the low mountain ranges in the Central American Isthmus and Mexico. Satellite sea surface temperatures (SST) imagery from MODIS for (A) May 8–15, 2000, and (B) February 26–March 4, 2000.

Sailfish Relative Abundance Data

Traditionally, relative abundance is expressed as the amount of catch resulting per unit of fishing effort (CPUE). Seasonal variability of sailfish CPUE off Central America is the result of several variables among which seasonal prey species abundance, prevailing oceanographic conditions that may enhance sailfish feeding, and the seasonal surfacing of the DO_2 minimum layer, the mixed layer, and thermocline should be the most important. The latter conditions significantly impact the seasonal habitat volume available for sailfish populations and their prey in the EPO, thus affecting sailfish population density, and consequently, catchability. Likewise, differences in fishing power of the vessels in the different fisheries affect the outcome of the CPUE.

Hinton and Nakano (1996) and Hinton and Maunder (2003) discuss habitat-based standardization (HBS) of CPUE for billfishes and tunas. That approach is appealing at resolving the definition of an index of relative abundance, which could be more appropriately used in explaining the seasonal dynamics of the sailfish abundance in the EPO off Central America. One significant constraint in using the HBS approach in the EPO off Central America is the need to understand the functional processes that result in the statistical linkages of the habitat explanatory variables and sailfish CPUE. Also the absence of a long time series of data to explain sailfish stock abundance and its linkage to the environmental explanatory variables does not facilitate the application of the HBS approach.

In this study, we use a January 1994–April 2005 nominal sailfish CPUE data series from a fleet of four billfish sport fishing vessels that were based at the Artmarina dock in Guatemala during that period, and the January 1994–December 2003 sailfish CPUE from Japanese industrial longline fleets (provided by the Secretariat of the Pacific Community with permission from the Japanese Government). The Guatemala sport fishery database consists of the number of sailfish "raised," the number of "bites," and the number "caught" during each fishing day. The number of sailfish raised per day fishing was the preferred nominal CPUE adopted in the analyses because of the significant linear correlation ($r^2 = 0.94$) found between the two nominal CPUE units and because only approximately 43% of the fish raised were actually caught ($CPUE_{caught} = 0.4349 * CPUE_{raised} + 9.5863$) (Fig. 5). Therefore, the CPUE in numbers raised per day may better reflect the true abundance of sailfish.

The number of sailfish raised during each fishing day in the sport fishery was pooled monthly for each of the four vessels. Because of the non-homogeneous nature of the sport fishing vessels and of the markedly dissimilar seasonality of the relative abundance we arbitrarily standardized the CPUE relative to the abundance in January 1994 and to the vessel with the most consistent historic operational record. A simple analysis of variance model as initially suggested by Robson (1960) was developed from a relative CPUE equation given as

$$CPUE_{ij} = (q_0 D_0) \cdot \frac{q_i}{q_0} \cdot \frac{D_j}{D_0} \cdot \varepsilon_{ij}$$

where i = vessel category, j = month, q_i = catchability coefficient in the i vessel in the fleet, q_0 = catchability coefficient of the vessel adopted as standard (i = 0), D_j = relative stock abundance in the j month, D_0 = relative stock abundance in the j month adopted as standard (j = 0), and ε_{ij} = error. The above equation is logarithmically transformed as

$$X_{ij} = \mu + \alpha_i + \beta_i + \eta_{ij}$$

where $X = \log_{10} CPUE$, μ = grand mean relative abundance ($\log_{10} q_0 D_0$), α = relative fishing efficiency effect ($\log_{10} q_i / q_o$), β = relative average stock abundance effect ($\log_{10} D_j / D_0$), and η_{ij} = lognormal error. The effects α_i and β_j are estimated by means of analysis of variance, and the standard relative abundance (CPUE) in each month (j) estimated by means of a bias-corrected anti-logarithm transformation such as

$$CPUE_j = 10^{\beta j} - 10^{\beta j} \cdot \frac{\sigma^2{}_j}{2}$$

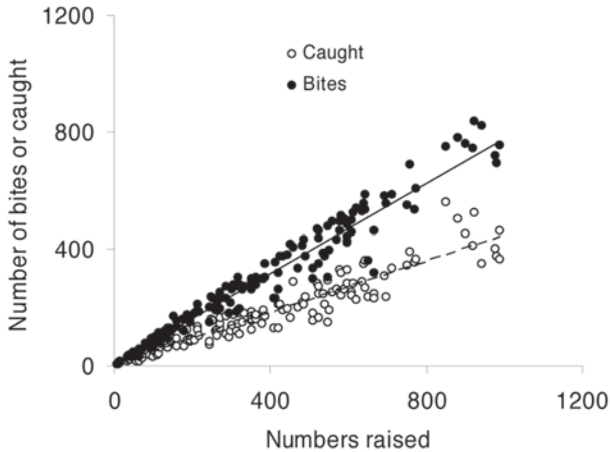


Figure 5. Relationships between number of sailfish (*Istiophorus platypterus*) raised and the number of bites and fish caught per day fishing in the sport fishery of Guatemala.

The fishing efficiency, or fishing power, of the three sport fishing vessels relative to the one selected as the standard resulted in 1.055, 1.059, and 1.20 and the standardized relative CPUE by month is given in Table 1 for the period January 1, 1994–April 30, 2005.

The historic CPUE for billfish in the Japanese longline fishery in the EPO reported by the Inter-American Tropical Tuna Commission (IATTC) for Areas 7, 8, and 9 (http://www.iattc.org/PDFFiles2/Bulletin-Vol.-22-No-4ENG.pdf) contains both sailfish and shortbill spearfish until 1994 and separated by species thereafter. However, sailfish comprised nearly 100% of the billfish caught in exploratory longline fishing surveys including Areas 7 and 8 of the IATTC including the EPO off Central America (Joseph et al., 1974, fig. 12). The CPUE for sailfish and shortbill spearfish of the Japanese longline fishery in this particular region were historically associated and analyzed by the IATTC and Joseph et al. (1974) as pertaining to sailfish only. However, Okamoto and Bayliff (2003; table 7) noted that starting in 1994, sailfish caught in the Japanese longline fleets were reported separately from shortbill spearfish and that most Japanese effort was absent from Area 7 while catches of the two species in Area 8 in the equatorial EPO were predominantly sailfish. The authors considered that previous reports were not adequate regarding the spatial and temporal distribution of these two species, especially under the consideration that catches of sailfish during 1994–1997 were the greatest in the western sections of the EPO but they represented only 10%–17% of the combined catch of shortbill spearfish and sailfish. For these reasons in our comparative analyses of the CPUE from the sport and industrial fisheries we used only the Japanese sailfish CPUE data approximately corresponding to Areas 7-2 and 8 of the IATTC for the period January 1994–December 2003 (provided with permission from the Secretariat of the Pacific Community). For further analyses of the historic sailfish CPUE trends in the EPO and trophy weights, we were forced to use historic CPUE data from Areas 7–9 of the IATTC, although they may contain deviations generated by the changes in abundance of the shortbill spearfish stock in the equatorial EPO.

Table 1. Relative standard sailfish catch per unit effort (CPUE) for the Artmarina-Guatemala sport fishing fleet.

Date	Relative CPUE	Date	Relative CPUE	Date	Relative CPUE	Date	Relative CPUE
Jan. 94	1	Jan. 97	0.641	Jan. 00	1.378	Jan. 03	0.642
Feb. 94	1.274	Feb. 97	0.947	Feb. 00	1.937	Feb. 03	1.201
Mar. 94	1.313	Mar. 97	1.38	Mar. 00	2.631	Mar. 03	1.644
Apr. 94	1.777	Apr. 97	1.565	Apr. 00	1.622	Apr. 03	1.028
May 94	0.884	May 97	1.658	May 00	0.993	May 03	0.831
Jun. 94	0.872	Jun. 97	0.958	Jun. 00	0.950	Jun. 03	0.670
Jul. 94	0.941	Jul. 97	1.257	Jul. 00	1.402	Jul. 03	0.978
Aug. 94	0.567	Aug. 97	0.477	Aug. 00	1.037	Aug. 03	0.375
Sep. 94	0.442	Sep. 97	0.404	Sep. 00	1.684	Sep. 03	1.621
Oct. 94	0.787	Oct. 97	0.676	Oct. 00	0.667	Oct. 03	0.915
Nov. 94	0.607	Nov. 97	0.868	Nov. 00	1.681	Nov. 03	0.933
Dec. 94	0.944	Dec. 97	0.712	Dec. 00	2.228	Dec. 03	0.788
Jan. 95	1.712	Jan. 98	0.878	Jan. 01	1.267	Jan. 04	2.199
Feb. 95	1.991	Feb. 98	1.237	Feb. 01	1.150	Feb. 04	1.953
Mar. 95	2.66	Mar. 98	0.700	Mar. 01	1.985	Mar. 04	1.378
Apr. 95	3.255	Apr. 98	1.316	Apr. 01	1.731	Apr. 04	2.040
May 95	1.283	May 98	1.637	May 01	1.624	May 04	1.933
Jun. 95	0.972	Jun. 98	2.245	Jun. 01	1.190	Jun. 04	0.370
Jul. 95	0.582	Jul. 98		Jul. 01	0.714	Jul. 04	0.258
Aug. 95	0.51	Aug. 98		Aug. 01	1.137	Aug. 04	1.097
Sep. 95	1.004	Sep. 98	0.383	Sep. 01	0.418	Sep. 04	0.902
Oct. 95	0.845	Oct. 98	0.574	Oct. 01	1.985	Oct. 04	1.212
Nov. 95	1.738	Nov. 98	3.457	Nov. 01	1.862	Nov. 04	1.101
Dec. 95	3.329	Dec. 98	3.206	Dec. 01	2.595	Dec. 04	1.695
Jan. 96	1.268	Jan. 99	3.039	Jan. 02	0.875	Jan. 05	1.305
Feb. 96	1.985	Feb. 99	3.908	Feb. 02	0.831	Feb. 05	1.635
Mar. 96	1.958	Mar. 99	2.337	Mar. 02	2.063	Mar. 05	1.430
Apr. 96	1.26	Apr. 99	1.759	Apr. 02	3.157	Apr. 05	1.229
May 96	0.925	May 99	1.117	May 02	1.386		
Jun. 96	1.167	Jun. 99	2.413	Jun. 02	0.978		
Jul. 96	0.809	Jul. 99	1.033	Jul. 02	0.933		
Aug. 96	1.497	Aug. 99	1.352	Aug. 02	0.744		
Sep. 96	2.2	Sep. 99	0.972	Sep. 02			
Oct. 96	0.964	Oct. 99	1.633	Oct. 02	0.650		
Nov. 96	1.629	Nov. 99	1.066	Nov. 02	0.693		
Dec. 96	2.313	Dec. 99	1.724	Dec. 02	0.748		

Sailfish Relative Abundance and Ecosystem Considerations

The sport sailfish relative abundance off Guatemala (Table 1) follows various seasonal trends that are not similar in intensity and appear negatively correlated with the mean sea level (MSL) observed in the neighboring area of Acajutla, El Salvador (http://ilikai.soest.hawaii.edu/uhslc/htmld/0082A.html) (Fig. 6). We previously observed that the dynamics of the MSL in this region are tightly related to the seasonality of the trade winds crossing the Central American region (Fig. 3) and this

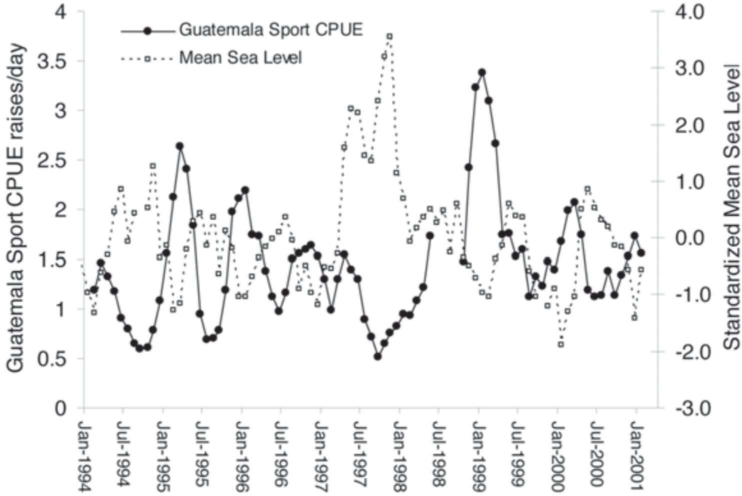


Figure 6. Seasonal dynamics of the mean sea level in El Salvador and the standardized relative seasonal abundance of sailfish (*Istiophorus platypterus*) in the sport fishery of Guatemala.

condition was exacerbated during the strong 1997 ENSO event (May–December 1997). The change in wind stress influences the local sea surface temperature directly by means of anomalous zonal advection, Ekman pumping (upwelling of cold water), evaporative cooling, and mixing. Also, it produces planetary (Kelvin) waves, which influence the depth of the thermocline, the mixed layer and the minimum DO_2 (Fig. 2). Due to significant changes in the wind patterns during ENSO (Fig. 6) from May 1997–December 1997, the MSL reached maximum levels due to the relaxation of the Papagayo jet winds (Fig. 3) while the relative abundance of the sailfish in the coastal regions was greatly dissipated. An atypical peak in sailfish CPUE occurred in late Spring 1998, most likely as an effect of the 1997–1998 ENSO, followed by another peak that began earlier in December 1998–February 1999 (Fig. 6). Therefore, the seasonality of the relative abundance of sailfish off Guatemala appears conditioned to the general ocean dynamics when habitat conditions are most compressed by the lowest MSL and significant surfacing of the thermocline, mixed layer, and the minimum DO_2. This seasonality may be associated with an increase in the population density of sailfish by way of habitat compression and/or changes in the abundance as a consequence of emigrations and immigrations according with optimal habitat use. Prince and Goodyear (2006) utilized archival tags to conclude that hypoxia-based habitat compression forces greater population density of tropical pelagic fishes, such as sailfish, in the upper portion of the water column. However, they did not explain the biological reasoning for the persistence of the species in the compressed habitat or the likelihood of migrations forced by the habitat compression. Therefore, we explored possible inshore emigrations and immigrations by analyzing the seasonal connectivity between the relative sailfish abundance in the more coastal regions off Guatemala and the relative sailfish abundance in the high seas corresponding to an area approximately between 5°S–20°N and to 120°W excluding the area off the Guatemalan EEZ. A consistent negative correlation between the two databases (Fig. 7) may be an indication of the linkages in seasonal relative abundance between the two regions. We also separated the effects of ENSO and non-ENSO years and estimated an average of the CPUE for each month for all the non-ENSO years separately for

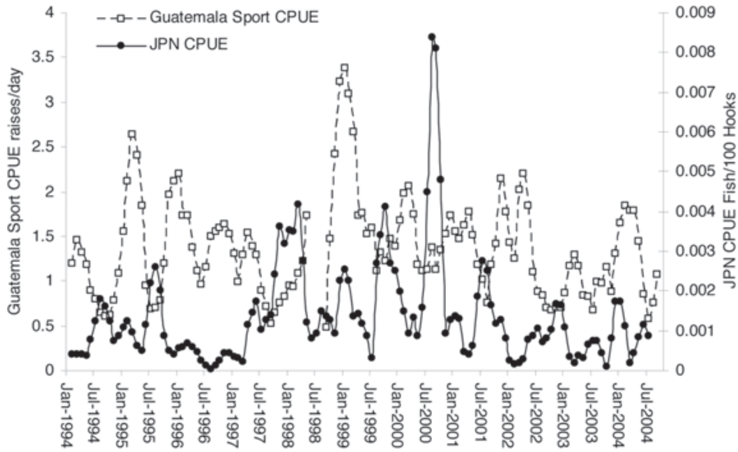


Figure 7. 1994–2005 monthly time series of the relative abundance of sailfish (*Istiophorus platypterus*) in Guatemala (raises per day) and the high seas Japanese relative abundance (number of fish per 100 hooks).

both regions. The resulting inshore-offshore seasonal linkages are evident in Figure 8A and there is a highly correlated regression between the Japanese CPUE in month t and the sport fishing CPUE in month t+4 ($CPUE_{sport\ (t+4)} = 658.62{*}JPN_{CPUE\ (t)+}0.407$; R = 0.957; Fig. 8B). The latter correlation is indicative of the consistency in the seasonal intensity of the linkage as well as of the timing of the potential migrations, implying that increased seasonal catch rates off Guatemala may be due to an increased abundance as well as increased density due to habitat compression.

The Role of the Prey Species

The seasonal migratory linkages described as a function of habitat change do not explain the biological reasons for the seasonal presence of the sailfish in the inshore regions off Central America. Very little is known about fundamental population processes of the sailfish in this area, such as their population age and size structure. Essential information, such as spawning dynamics, individual age and growth, and maturity remain to be elucidated, hampering attempts to explain the population processes. Therefore, an effort was made to integrate data of opportunity that could explain the seasonality of the sailfish in the EPO off Central America. In this regard, results of Soviet cooperative fishery investigations carried out in Nicaragua (Bendik et al., 1987) found that sailfish caught off the Pacific coast of Nicaragua were all in a feeding mode with no sign of spawning activity. The authors also reported that sailfish stomachs were in a high degree of fullness and contained exclusively squids and small schooling pelagic fish species such as thread herring and other clupeids. These findings agree with the results of Hernandez et al. (1998) who analyzed the food consumed by 77 sailfish caught in Nicaraguan waters and provided the first quantitative measure of the likely prey consumed by the sailfish: 81.8% of squids, 11.7% thread herring, 2.6% juvenile sharks, 2.6% of skipjack tuna, and 1.3% of other small pelagic species. Consequently, sailfish in the EPO off Nicaragua show a seasonal feeding stage and appear to prey mainly upon two distinct groups: squids and clupeids.

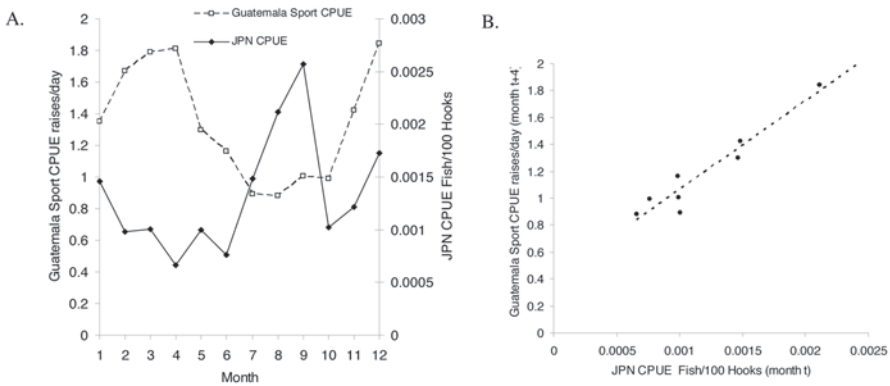


Figure 8. (A) Average 1994–2005 monthly relative abundance of sailfish (*Istiophorus platypterus*) in the sport fishery of Guatemala during non-ENSO years and the corresponding Japanese average monthly relative abundance in the high seas, in number of fish per 100 hooks. (B) the relationship between the two relative abundance variables.

Sailfish gut content studies conducted in Mexico from north of the Gulf of Tehauntepec to the Baja California Peninsula (Evans and Wares 1972); both Eldridge and Wares (1974) and Rosas-Alayola et al. (2002) revealed that squids, paper nautilus (*Argonauta* spp.), Pacific threadfin (*Polydactylus* spp.), round herring (*Etrumeus* spp.), cornetfish (*Fistularia* spp.), and frigate tuna (*Auxis* spp.) were the most common prey (Evans and Wares, 1972; Eldridge and Wares, 1974; Rosas-Alayola et al., 2002). These differences in the reported regional sailfish diets suggest that sailfish feeding may be opportunistic, and that the adjacent Central American and Mexican regions have different prey regimes with different food availabilities.

Soviet assessments of the pelagic resources in the Pacific off Nicaragua (Ministry of the Fishing Industry of the USSR, 1988) show that thread herring, *Opisthonema libertate* Günther (1867) was the predominant species with a biomass varying seasonally between 23–31 thousand mt. The vertical distribution of this biomass was found to be 15% in the upper 30 m, 80% between 31–50 m, and 5% between 51–100 m, and was limited to areas on the continental shelf where DO_2 levels were between 3–4 ml L^{-1} and severely constrained by the shallow minimum DO_2 in the region. Schools of *O. libertate* varied 2–7 m in the vertical and 10–55 m in the horizontal forming up to 4 schools per km^2 during the day and dispersing at night.

On the other hand, Norwegian exploratory fishery research surveys carried out in the coastal regions of the EPO from Colombia to Mexico during 1987 (NORAD/UNDP/FAO, 1988) generated the only existing comprehensive seasonal assessment of the abundance and distribution of the pelagic species that may be the primary prey of sailfish. The results show that the deep bodied thread herring, *O. libertate*, was one of the dominant species in the shallow water communities (15–75 m), together with other clupeids of the genera *Opisthopterus* and *Neoopisthopterus*, while the dart squid, *Loliopsis diomedae* Hoyle (1904), was common in the intermediate shelf at depths 50–100 m. It is reported that these pelagic species form a continuous distribution from Nicaragua, through the Gulf of Fonseca and El Salvador, and that the small pelagic species formed mainly by clupeids may form a single stock between Guatemala and the Gulf of Tehuantepec in Mexico. The seasonal relative abundance of these resources appear to form denser but discontinuous distributions in the first

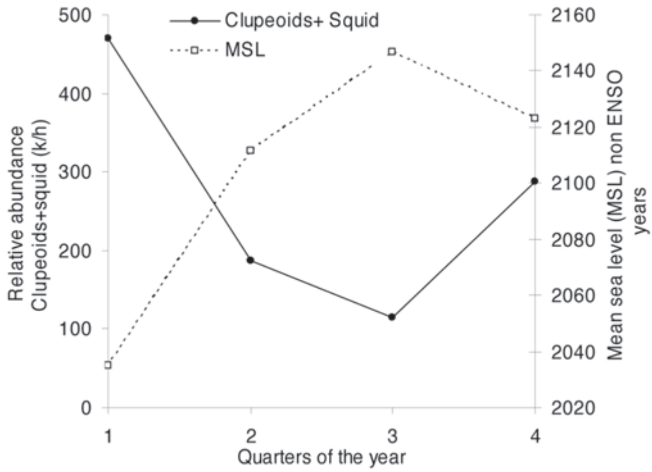
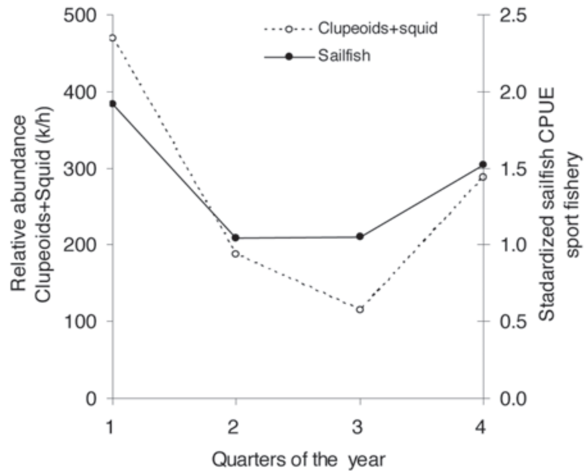


Figure 9. Trends in quarterly relative abundance of clupeids and squid resources in the Nicaragua-Mexico coastal regions (adapted from NORAD/UNDP/FAO, 1988) and mean sea level (MSL) in El Salvador.

and last quarter of the year and are more evenly distributed with much lower densities during the second and third quarter (NORAD/UNDP/FAO, 1988, table 3.9.1). The Norwegian and Soviet studies both emphasize the importance and dominance of the abundance of clupeids and squids in the region.

Comparison of the quarterly relative abundance of clupeids and squid provided in the NORAD/UNDP/FAO (1988) report with the MSL abundance data off El Salvador corresponding to the same quarters of the year suggests that most of the seasonal variability of the relative abundance of the clupeoids+squid species is negatively correlated to the MSL (Fig. 9). Thus, the seasonal oceanographic features observed in Figures 2 and 4 may play a major role in the dispersion and concentration of the pelagic prey species, such that their greatest densities occur in the first and fourth quarters of the year when major oceanographic features are fully developed in the region. This temporal-spatial distribution of the clupeoids and squid relative abundance is reflected in a similar relative abundance pattern observed in the sport fishery off Guatemala during 1994–2005 (Fig. 10A) and the average Japanese sailfish CPUE in IATTC Area 7.2 in 1956–1970 found in Joseph et al. (1974; fig. 10)(Fig. 10B). Although the relative abundances of predator and prey plotted in Figure 10 do not coincide in terms of years or decades, their average seasonal behavior is strikingly similar. In fact a highly and positively correlated linear relationship exists between the quarterly relative abundance of the prey species and that of the combined Guatemala sport 1994–2005 and Japanese 1956–1970 sailfish CPUE in IATTC Area 7.2 ($CPUE_{sailfish,t}$ = 0.4811* Prey Abundance$_t$ + 0.1297; R^2 = 0.946; Fig. 11). Therefore, it is likely that the seasonal increase of the relative abundance of the sailfish in the inshore regions of the EPO off Guatemala during the first and fourth quarters of the year may be related to prey densities which are the highest due to seasonal pelagic habitat compression. The breaking up of the oceanographic features observed in the region during the second and third quarters of the year should result in dispersion of the prey and of sailfish.

A.



B.

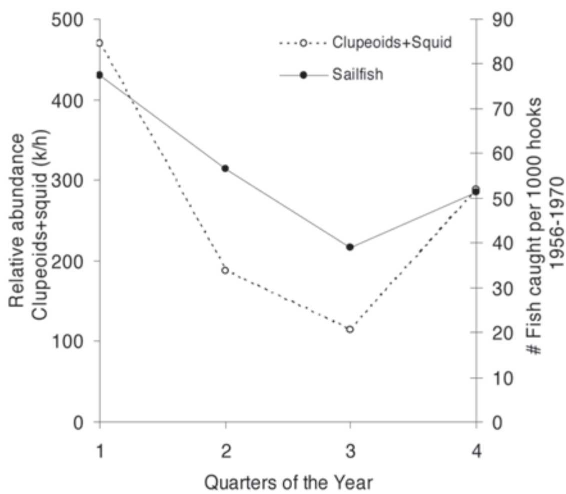


Figure 10. (A) Relative quarterly abundance of clupeoids and squid in the Nicaragua-Mexico region and the average relative abundance 1994–2005 of the sailfish (*Istiophorus platypterus*) in the Guatemalan sport fisheries during non-ENSO years. (B) The same abundances based on the Japanese 1956–1970 relative abundance estimates for IATTC Area 7.2 (adapted from Joseph et al., 1974).

Relevance of the Historic Trends in Relative Abundance

One of the most important requirements for a successful sport fishing industry is access to fishery resources that are abundant to provide high catch rates, and access to trophy size fish to enhance the sport fishing experience. In the case of the sailfish in the EPO off Central America, high sport catch rates still occur (Fig. 1) despite significant impact that initial 1964–1980 Japanese long-lining had on the relative abundance of the coastal sailfish stock in Areas 7-2 and 8 of the IATTC (Miyabe

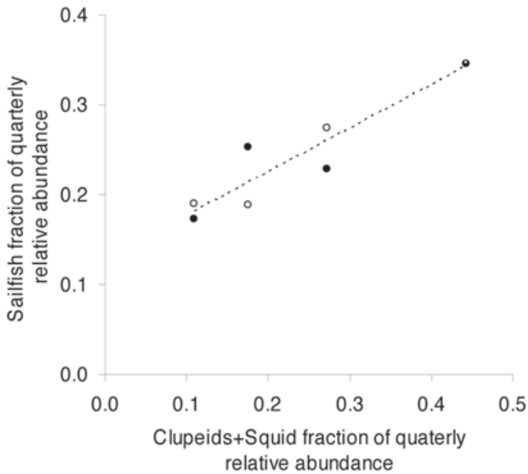


Figure 11. Functional relationship between the relative abundance of the prey species and of sailfish (*Istiophorus platypterus*) in the 1956–1970 Japanese longline fisheries in IATTC Area 7.2 (closed circles) and 1994–2005 sport fishery of Guatemala (open circles) combined.

and Bayliff, 1987, fig. 29). During that period, sailfish CPUE decreased about 73%. Although Japanese longline fishing effort in the EPO off Central America (IATTC Area 7-2) decreased considerably during the 1980s, its effort was concentrated in the equatorial EPO (IATTC Areas 8 and 9). We have shown a likely seasonal linkage between the coastal Central American and the high seas sailfish resources (Figs. 7,8). Therefore, the ongoing high seas fishing operations coupled with coastal longlining for mahi-mahi and tuna should be cause for concern that sportfishing catch rates may decline because sailfish are incidentally caught at significant rates by coastal longliners. This is especially worrisome given that sailfish population density may not directly equate to high population abundance in habitat restricted areas such as in the EPO off Central America. Therefore, despite current high sportfishing catch rates, overall abundance of the resource may be declining due to high overall population exploitation.

The trends of uncorrected sailfish and shortbill spearfish CPUE published by the IATTC for Areas 7–9 in the EPO and the trend in sailfish trophy size in the EPO obtained from the Book of World Fish Records published by the International Fish Game Association (IFGA) show that during the period 1970–1995, the average sailfish relative abundance decreased 82% while trophy size decreased by over 35% (42% in 1993)(Fig. 12). Although the Japanese CPUE for sailfish for Areas 7–9 contains a fraction of shortbill spearfish, which may be lower than the same statistics for the Central Equatorial Pacific, the trends are remarkably similar. Therefore, the combined impact of high seas and coastal industrial fisheries and the added sport fishing activities based on the sailfish resource in the EPO may compromise the future sustainability of this economically and socially important species.

Conclusions

The marine ecosystem in the EPO off Central America encompasses complex oceanographic features emerging from three wind jet systems (Tehuantepec, Papagayo, and Panama) that have significant seasonal characteristics. The seasonal inten-

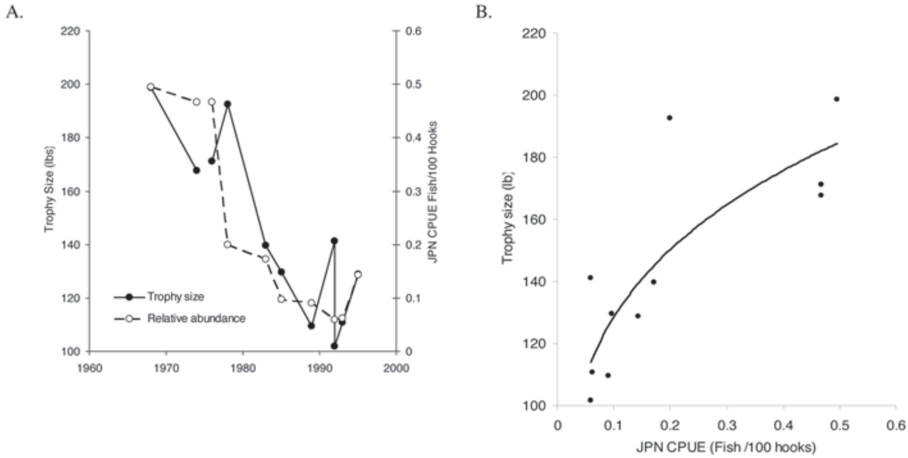


Figure 12. (A) Historic depletion trends of the sailfish (*Istiophorus platypterus*) relative abundance in the EPO and of the trophy size in the EPO, and (B) functional relationship expressing the depletion trends in abundance and the resulting decrease in sailfish trophy size.

sity of these wind jets create local seasonal upwelling reaching over 100 mi off the coast and their combined effects are observed in significant changes in thermocline and mixed layer depths. Concurrently, interruption of coastal currents by these seasonal events and the formation of cyclonic and anti-cyclonic eddies have pronounced implications for the general marine productivity of the region. One of these effects is the seasonal population distributions of pelagic species in the lower levels of the food chain, which expand and contract in association with the DO_2 limited pelagic habitat.

Based on the few observations available, sailfish in the EPO off Central America appear predominantly in a feeding stage, preying mainly on clupeoid and squid species characteristic of the region. Sailfish abundances are significantly correlated with seasonal prey species concentrations. Because of the contraction of the pelagic habitat during the northern winter months, sailfish occur in the highest densities in this region at that time, providing a unique opportunity for sport fishing activities given that higher densities are associated with increased catchability and high catch rates. High catchability and high catch rates of the sailfish resource base have prompted major regional investments in new sport fishing facilities that use the tourism sector for promoting these activities. The local economic and social impacts of such development are in the hundred of millions of dollars. However, these activities are in direct confrontation with very large tuna and mahi-mahi fishing operations in the EPO where sailfish is caught incidentally. Effective management of the sailfish (and other billfish resources) requires defined objectives and reliable information about the likely consequences of management actions, or lack of such actions.

Given the large longline fishing capacity presently deployed in the EPO off Central America and in the high seas, the relative abundance of the sailfish resource has decreased by more than 80% in the last 35 yrs while sailfish trophy size has decreased over 35% in the same period. The general lack of appropriate information on the population dynamics of the sailfish in this region and the lack of impetus to assess the status of exploitation of an incidental species in major regional tuna fisheries create one of the most formidable stumbling blocks to set regional policies that countries in Central America can commonly adopt to conserve this economically and socially important resource.

Results of this study clearly indicate the ecosystem implications in the exploited sailfish population dynamics and the need for a more comprehensive approach to manage the resource. For this to be a reality, there are several needs: (a) a regional strategy should be established, such as policy development and enforcement that can effectively control and manage the existing fishing practices; (b) research on the primary biology of the sailfish and the prey species needs to be initiated and a long term plan to conduct this work should be established; (c) assessing the status of exploitation of the sailfish is required if longer range sustainability of this resource is expected; and (d) an ecosystem approach to sailfish fisheries management requires a better understanding of bio-physical interactions, control of incidental exploitation, and definition of priorities in the use of the fishery resources in the region such that economic development is not marred by the misuse of uniquely available resources. Overcapacity in the existing longline fishery is a threat to the sustainable use of the billfish resources in Central America and it conflicts directly with the sustainability of sport fishing activities. As such, a regional policy and research organization acting under a regional fishery management agreement is becoming mandatory if sound economic use of the existing billfish fishery resources is expected.

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