Seasonal availability of sailfish in sport fisheries in Guatemala contrasts significantly with sport billfish catch rate trends in other countries in the region

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Introduction

Sailfish, *Istiophorus platypterus*, is the smallest of the billfish species of interest to pelagic sport fishing groups in the Eastern Tropical Pacific Ocean (ETPO)(Fig. 1).

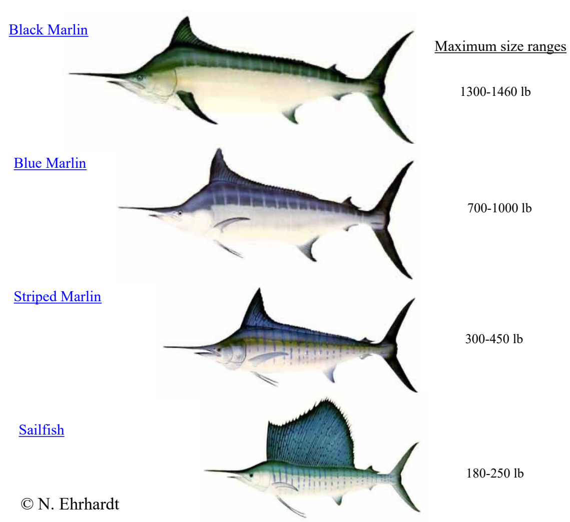


Figure 1. Comparative size of main billfish species in sport fisheries in the ETPO.

Sailfish is distributed world-wide but more prominently in the coastal regions of the ETPO between Mexico and Panama (Fig. 2). This spatial population characteristic makes sailfish more accessible to sport fishing fleets that operate from sport fishing facilities in the Central American Isthmus and Mexico.

In the ETPO, sailfish sport catch rates are the highest in the world (Fig. 3) and this is in spite of the fact that sailfish is caught as bycatch in large commercial fishing operations that mostly exploit tuna and mahi-mahi, *Coryphaena hippurus,* using purse seines and industrial longlines (Fig. 4).

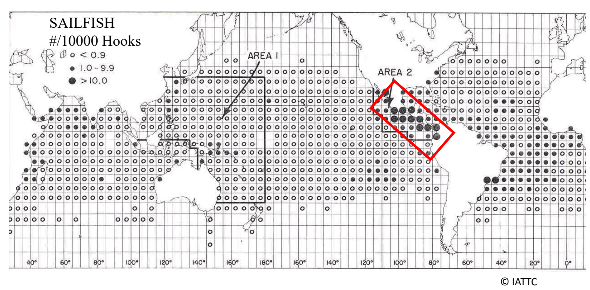


Figure 2. Sailfish global relative abundance

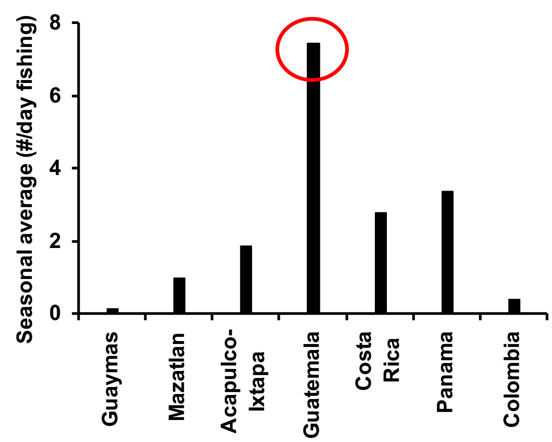


Figure 3. Sailfish catch rates in numbers per day fishing in the ETPO

It is noted however, that significant differences in sport sailfish catch rates exist among the ETPO countries due mostly to differing seasonal habitat and oceanographic conditions that effect the historic availability and catchability of the species in the sport fisheries. The objective of this review report is to present summarized information that explains the magnitude as well as the seasonal dynamic differences of sailfish catch rates that sustain extraordinary billfish sport fisheries in the region. Most of the scientific information included in this report was produced by the University of Miami Billfish Research Group headed by Drs. Nelson Ehrhardt, Mark Fitchett, Bruce Poholot and Julie Brown. Results of ongoing billfish research by Dr. Ehrhardt is also incorporated.

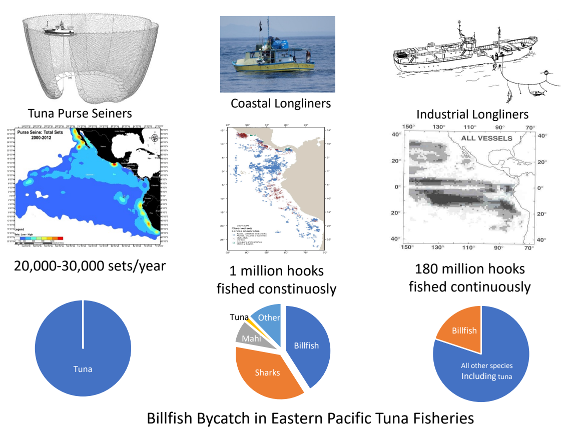


Figure 4. Fisheries targeting tuna and mahi-mahi that capture sailfish incidentally

Historic sailfish exploitation in the ETPO

In the ETPO, sailfish are subjected to significant by-catch in massive tuna and mahi-mahi longline fishing operations (see pie diagrams at the bottom Fig. 4). For this reason, and in order to understand the present day needs for sailfish conservation, it is important to elaborate on the historical evolution of such fisheries in the Pacific Ocean. As it stands, incidental out-of-control and unregulated exploitation of sailfish in longline fisheries may be unsustainable in the longer term.

From a historical point of view, longline tuna fishing operations in the ETPO were the result of the expansions of Japanese and South Korean industrial fishing fleets during the 1950s, and those of Taiwan in the 1960s. Subsequently in the 2000's, with the advent of China's global economic development, a significant spatial advance and hegemony of Chinese fishing fleets in the ETPO have been observed. In sum, over 180,000,000 hooks were deployed in recent years in longline fishing operations in the ETPO (Fig. 5).

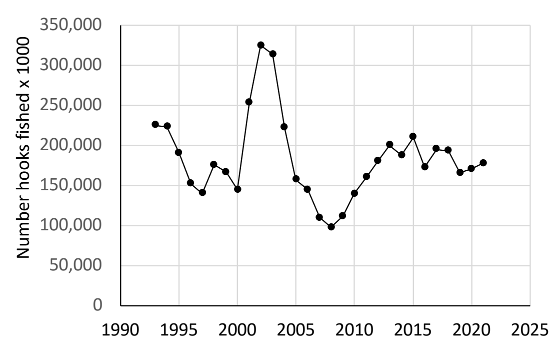


Figure 5. Amount of fishing effort in millions of hooks fished by all longline fleets in the ETPO as reported by the IATTC

A very abstracted list of historic events indicate that as a consequence of Allied Power supremacy toward the end of World War II, Japan experienced a severe shortage of the resources necessary for effectively continue operations of their large tuna fisheries of the 1930's in the Western Pacific Ocean. In fact, Japanese industrial fisheries ceased to operate following Japan's unconditional surrender in August 1945, when a total ban on navigation by all Japanese vessels was imposed. At that time Japan had lost its entire mothership fleet that provided support to their long-distance tuna fishing fleets, as well as most of its tuna fishing fleet that was then controlled by the Allied Power and directed to provide fresh food to the Allied occupation forces. Furthermore, Japan was stripped of all overseas territories, as well as the Ryukyo Islands to the USA resulting in the loss of all Japanese tuna fishing grounds (Konuma 1998 in Swartz 2004).

It followed that under the authority of the Supreme Commander of the Allied Power (SCAP), headed by General Douglas MacArthur, the Japanese fishing industry was targeted as critical to provide an important source of animal protein for a country facing severe food shortages while relieving the United States of burdensome aid expenses and as well as allowing Japan use fish products for export in order to meet its financial reparations to the allied countries (Iwasaki 1997 in Swartz 2004). The rebuilding of fisheries-related industries such as ironworks and shipbuilding was planned by the SCAP as a stimulus to the recovery of Japan's economy (Smith 2003 in Swartz 2004). For this purpose in 1946, the SCAP authorized the construction of 795 steel fishing vessels and as well as the operation of Japanese offshore and distant water fleets within a narrowly defined area that was known as the MacArthur Line (Fig. 6 left). As a result of these events, Japanese fisheries operated in approximately 40% of the areas to which they had access in the pre-World War II period; however, the reconstruction plan significantly helped to re-establish distant water tuna fishing operation capabilities and by 1949 Japan fishing capacity had already exceeded its pre-World War II operational and production levels and the MacArthur line regulation was abolished in that year (Morita 1998 in Swartz 2004).

As a result of the efforts to rebuild Japan's economy in the post-war period, Japanese longline fleets were established to fish for large pelagic species that by 1960 had occupied large regions of the ETPO. The fishing "colonization" of the tropical Pacific Ocean by Japanese fleets was completed by the mid 1960's with the arrival of longline fishing operations in international waters off South America in 1964 (Fig. 6 right data from IATTC).

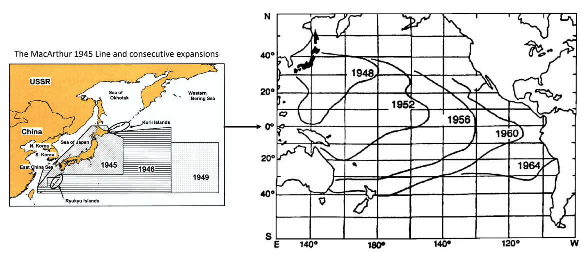


Figure 6. Historic spatial development of Japanese longline tuna fisheries in the ETPO

Other Asian nations, especially South Korea after the signing of the 1953 armistice signaling the end of the fratricidal war combats with North Korea, established operations with industrial longline fleets engaged in tuna fishing in the Pacific Ocean beginning in 1955. Such developmental effort was supported in part by transferring Japanese technologies and investments, while at the same time South Korean traditionally complex industrial corporate conglomerates simplified their economic and financial structures in support of the post war reconstruction efforts (Swartz 2004). Similarly, longline fisheries development was followed by fleets of industrial longliners from Taiwan in the 1960s using longline technologies spared from Japanese fisheries. As a result of these developments in Pacific high seas fisheries, sailfish catch rates in the tropical Pacific Ocean fisheries drastically declined (Figs. 7 and 8). It can be concluded from these figures that present day sailfish abundance in the ETPO is at an historically significant low level.

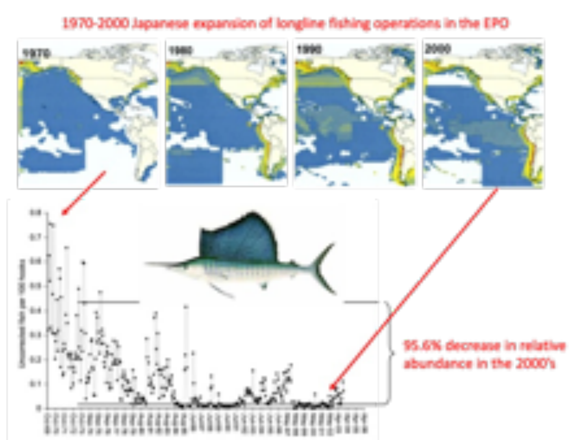


Figure 7. Historic spatial development of Japanese fisheries in the ETPO and trends in sailfish catch rates in Japanese longline fleets (Data from IATTC and Swartz 2004)

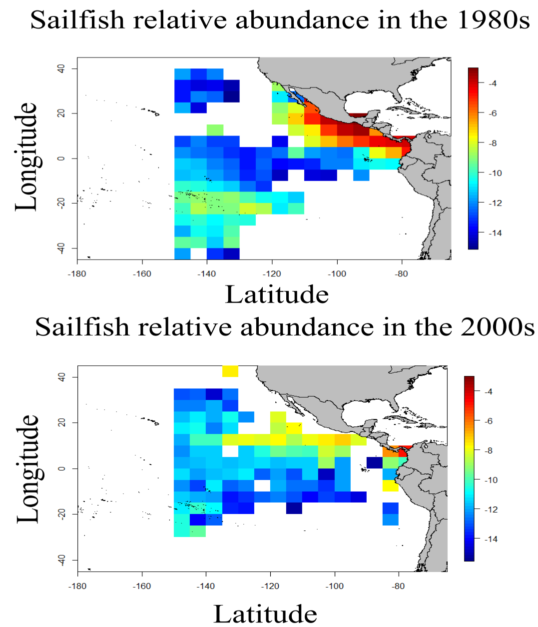


Figure 8. Historic spatial distribution of sailfish indicating depletion of regional catch rates estimated from Japanese catch statistics available through the IATTC (UM Billfish Research Group)

The long-term exploitation impact of sailfish is also reflected in significant declines in historical trophy sizes and average declines in the relative abundance of the species in the ETPO (Fig. 9). Indeed, there is a considerable historical decline of 60% in sailfish trophy sizes and 47% in their relative abundance globally in the region.

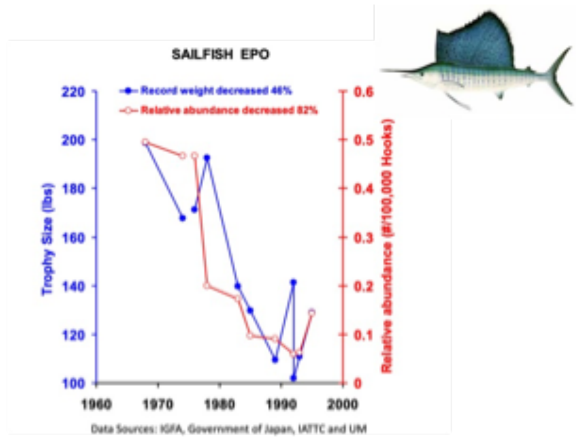


Figure 9. Sailfish trophy size and catch rates in the ETPO (IATTC, IGFA and UM Billfish Research Group)

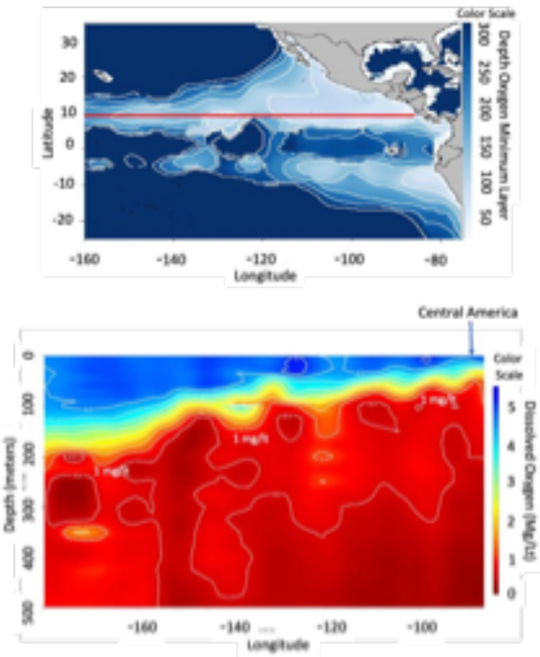


Figure 10. Spatial and depth distribution of oxygen deficient regions in the ETPO (Upper) and vertical distribution of dissolved oxygen (Lower) along red line at approximately 10N Latitude (Data World Ocean Database and UM Billfish Research Group).

Billfish ecosystem in the ETPO

Billfish are active migratory predators, sailfish in particular may exhibit burst swimming speeds of up to 67 nm/hr. (Pohlot and Ehrhardt 2017; Pohlot 2017). Such behavior should translate in significant energy requirements and high oxygen consumption levels. Main sources of oxygen enter the ETPO habitat at the surface—either directly from the atmosphere or from significant surface-dwelling phytoplankton producing it during photosynthesis.

In contrast with oxygen production by phytoplankton photosynthesis, the ETPO contains two of the three largest oxygen deficient zones (ODZs) observed in the world oceans, with concentrations of dissolved oxygen that are low to negligible at mid-ocean depths between approximately 35 to 1,000 meters below the surface. Those two regions are found off the coasts of Mexico to Central America and off the coast of Peru (Fig. 10 Upper).

ODZ regions have a poleward undercurrent, the California Undercurrent (CUC) in the Northern Hemisphere and the Peru-Chile Undercurrent (PCUC) in the Southern Hemisphere, which flow near the continental shelf and spawn mesoscale eddies that propagate west through their ODZs. Such mesoscale eddies contribute to the increase of ocean productivity by transporting upwelled nutrients from the depths that stimulate an overgrowth of algae (i.e., phytoplankton), which then sinks and decomposes in the water. The biomass decomposition processes consume oxygen and deplete the oxygen supply available to sustain marine life.

Therefore, ODZs occur due to a combination of nutrient-rich upwelling, slow-moving mixing, and high biological surface productivity followed by oxygen depletion by algal and fish biomass decay. In the ETPO these regions are found in the subtropics North and South along the equator (Fig. 10 upper).

Levels of dissolved oxygen have a major role in structuring marine ecosystems. Hypoxic, or low dissolved oxygen zones, in the ETPO create vertical stratifications of the water column (Fig. 10 lower) forcing the pelagic fish to concentrate in the more oxygenated surface layers. Such dynamic ecosystem structuring is designated as habitat compression. In the easternmost regions of the ETPO habitat compression is at its maximum where suitable fish habitable depths are above 40 to 60 meters from the surface. Toward the western portions of the ETPO, habitat compression is less severe where oxygen depletion is mostly found in the upper 150 meters (Fig. 10 lower).

Habitat compression is a forcing mechanism that functionally concentrates fish population biomasses in more reduced ecosystem volumes. Under those habitat forcing conditions, fish populations are exhibiting markedly higher population densities closer to the surface facilitating exploitation of the renewable resources by means of pelagic fishing gear. In those regions, billfish prey species are more concentrated and shoaling billfish species exhibit higher availability and catchability, two conditions that promote sport billfishing in the Central American region.

Satellite tagging of sailfish in the ETPO has generated important data in terms of the limits of hypoxia that the species can withstand in the region. Figure 11 shows that satellite tagged sailfish by the University of Miami Billfish Research Group, migrated more linearly and at a faster pace when crossing areas of significant lower temperatures due to upwellings off Mexico and Nicaragua-Costa Rica. Tagged sailfish adopted a food searching mode expressed by more often changing direction and speed when inhabiting in off-upwelling areas.

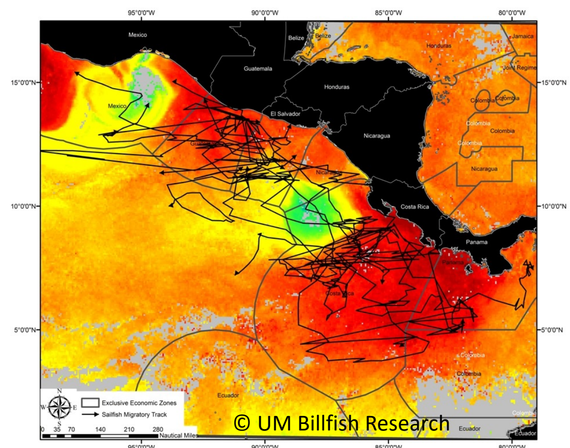


Figure 11. Sailfish satellite tag tracks through stratified temperatures and dissolved oxygen off Central America (Data and analyses by UM Billfish Research Group)

Depth residency of the satellite tagged sailfish occurred mostly between 0 and 50 meters with increased residence in areas where dissolved oxygen levels were above 2.5 mg/L. Residence depths varied regionally as a function of depths of the minimum dissolved oxygen depth (Fig. 12). This is in contrast with satellite tagged sailfish data available from other regions of the world oceans not affected by hypoxia indicating that sailfish can reach diving depths well over 1000m. Therefore, the amount of dissolved oxygen compressed toward the surface layers in the ETPO is a fundamental factor which limits the vertical distribution of sailfish prey in that region.

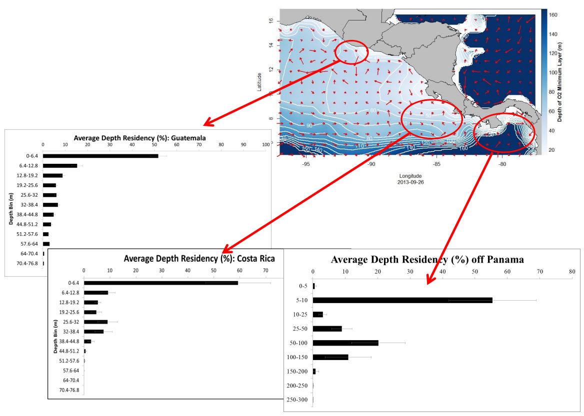


Figure 12. Times spent by satellite tagged sailfish at different depths and regions (Data and analyses by UM Billfish Research Group)

Seasonal availability of sailfish in the ETPO to recreational fisheries

Winds from the Gulf of Mexico and Caribbean Sea blow seasonally through the low mountainous passages in Mexico (the Tehuano winds), Costa Rica-Nicaragua (the Papagayo winds) and Panama (the Panama Canal winds) that displace surface waters of the Pacific Ocean away from the coasts creating conditions of seasonal upwelling of deep colder nutrient rich waters in the ETPO off Central America and Mexico during the Northern Hemisphere winter (Fig. 13). Therefore, the vertically viable but highly compressed habitat for tuna, billfish, sharks, and all other pelagic species are further horizontally stratified by the summer-to-winter upwelling changes due to the variable intensity of the trade winds.

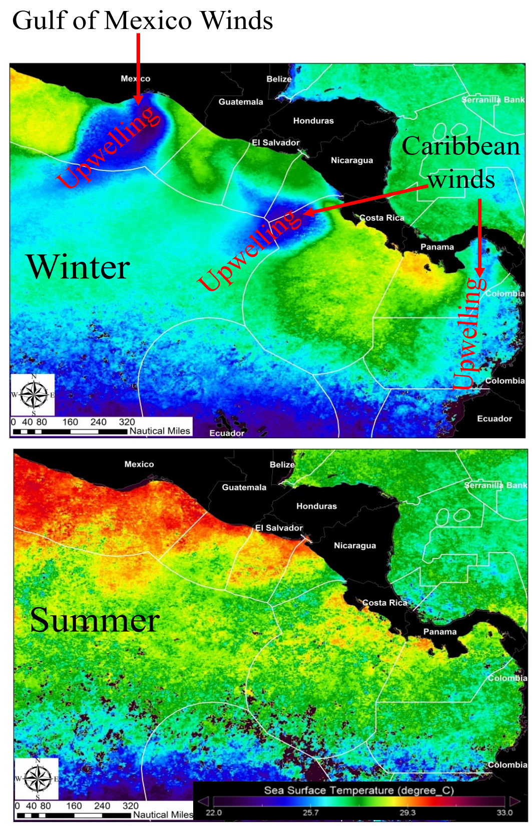


Figure 13. Seasonal intercontinental winds effect on seasonal sea surface temperatures due to upwelling in the ETPO

Consequently, in the ETPO sport fisheries depend to a great extent on prevailing vertical and horizontal stratified habitat compressions forcing seasonal changes in the billfish population densities. As shown in figures 14 and 15 this is particularly significant in the seasonal dynamic character of billfish sport fisheries of Guatemala. During May-October extended Tehuano wind relaxations effect the flow of the Costa Rica Coastal Current (CRCC), when it flows predominantly eastward beyond the shelf while nearshore the coastally trapped surface inflow from the southeast penetrates across the entire head of the Gulf of Tehuantepec. During November-March there exist a significant spin-up of anticyclonic eddies generated by the significant response of the central Gulf of Tehuantepec to the Tehuano wind offshore forcing events. It is suggested that at this time the CRCC turns offshore at the Gulf (Fig. 14).

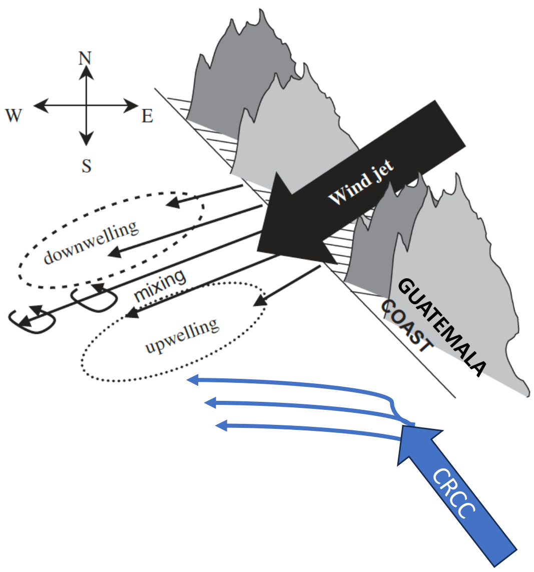


Figure 14. Sketch of the Tehuano wind forcing of surface waters off the Gulf of Tehuantepec and potential seasonal deflection of the CRCC offshore (Adapted from Samuelson and O'Brien 2008)

At this time the near-shore circulation has a more direct effect on local fisheries and coastal ecology resulting in an accumulation of billfish prey biomass off the coast of Guatemala and Mexico (Fig. 15) and creating a significant inter seasonal cycle of sailfish relative abundance as function of the horizontal stratification created by Tehuano wind events (Figs. 16 results in this report).

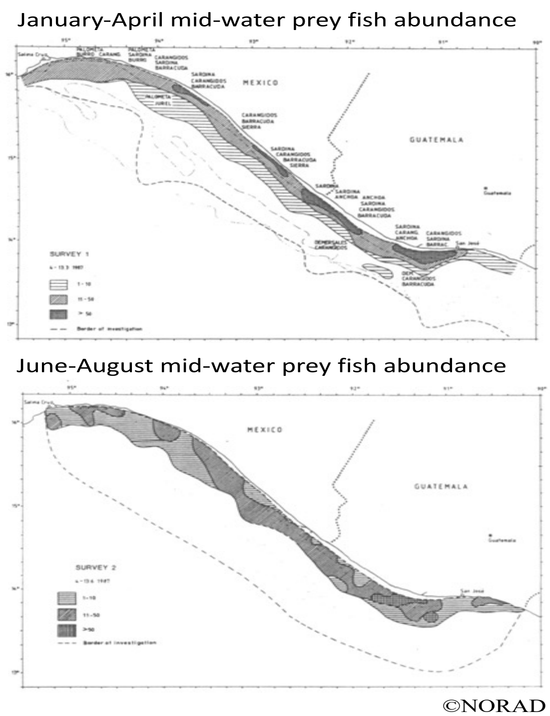


Figure 15. Seasonal distribution of small mid-water sailfish prey fish species abundance with significant Winter stratifications off Guatemala and more uniformly distributed during Summer from Guatemala to Mexico (Data from NORAD)

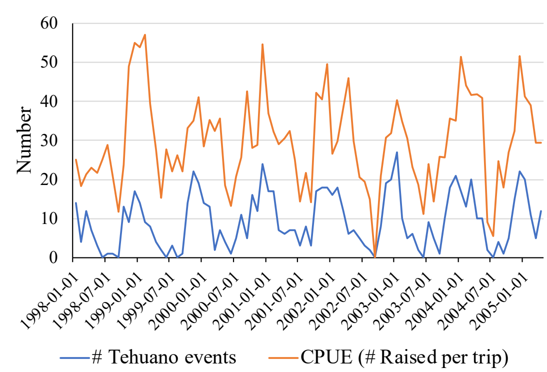


Figure 16. Seasonal number of Tehuano wind events and number of sailfish raised per day fishing in sport fisheries in Guatemala (Ehrhardt this report research results)

In Panama, mean sea level measured at the Pacific entrance of the Panama Canal reflects the changes in the seasonal intensity of Panama Canal winds passing through from the Caribbean Sea. Black marlin caught and released by Tropical Star Lodge sport fishing fleets based at Piñas Bay in the Darien Province of Panama is significantly more available at the end of the relaxed Panama Canal winds periods and start of the upwelling (i.e., winds from the North) season during January to March (Figs.17 and 18). However, as lower temperatures generated by upwelling intensify, the entire coastal portion of the Gulf of Panama south of Piñas Bay and beyond the Panama Economic Exclusive Zone become significantly more habitat compressed and black marlin catch rates also decrease very significantly (Fig. 17). It is possible that black marlin migrate out of the coastal areas of the Gulf of Panama when Southerly winds start blowing North in April-May reaching a peak in October (Fig. 18). A similar situation occurs with sailfish in this region (see Fig. 23).

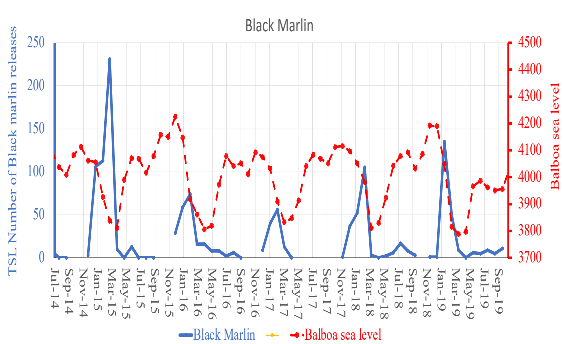


Figure 17. Sea level measured at Balboa and black marlin releases during the January-March sport fishing seasons in Eastern Panama

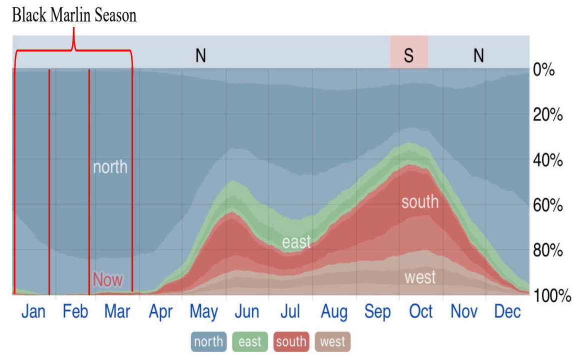


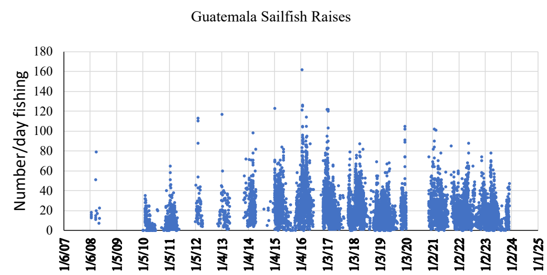
Figure 18. Seasonal direction and percent prevalence of winds in the Gulf of Panama and black marlin seasonal sport fisheries (Data from Panama Government Agencies)

Comparison of regional Sailfish catch rates

In the previous sections, it is shown that billfish population densities react to permanent levels of vertical habitat compression and seasonal horizontal stratifications that appear to control distributions of the billfish prey species. Catch rates of sailfish, the most coastal of the billfish species, have a greater preponderance in nearshore sport fisheries, reflecting changes in their availability due to prevailing seasonal oceanographic and atmospheric mechanisms that regulate their prey species distribution. This section uses historical sailfish data reported for three regions in the ETPO. For Guatemala I use historical statistical information from the former Fin and Feathers Resort and the current fishing operations from Casa Vieja Resort fleets. For Costa Rica, the statistical data provided for the fleets of Crocodile Bay Resort in Eastern

Costa Rica and the Costa Rica Club Náutico de Pesca are used, while data from fleets at Tropic Star Lodge in Piñas Bay, Darién Province in Panama, are used. Existing data consist of number of sailfish raised during a fishing trip, sailfish caught-and-released per fishing trip, total number of sailfish released by monthly periods, and monthly landings realized in Costa Rica by industrial longline fleets. Ehrhardt and Fitchett (2006) argue that sailfish statistics collected per fishing trip may mean two different conditions. Counts of sailfish raised per trip should better reflect the local abundance and availability of the resource in the area while the numbers caught-and-released per trip should represent the catchability of the available resource. The sailfish catch rates comparisons that follow in this section use all available historical statistics that are defined as valid of the sportfishing processes.

Historic daily sailfish statistics reported by individual sport fishing boats for the period 2008-2023 in Guatemala (Fig. 19) show consistent seasonal distributions of both raised as well as caught-and-released sailfish. Missing data between March-December of 2020 is due to an alt of fishing operations during the COVID19 epidemic. The daily fishing data for the 2008-2023 period have an overall average of 19.9 fish raised and 10.5 fish caught-and-released per trip, respectively.



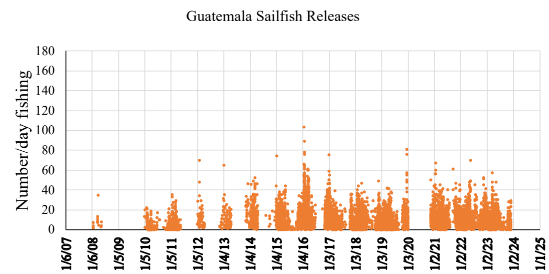


Figure 19. Daily sailfish raised and caught and released per fishing boat per fishing trip during 2008-2023 in the Guatemalan sport fishery obtained from Casa Vieja fishing statistics

The annual averages of raised and caught-and-released sailfish are presented in figure 20 for the compounded Fin and Feathers and Casa Vieja catch data series. The first set originated from fishing fleets operating during 1994-2005, while the second set corresponds to catch for the period 2008-2023. Throughout the entire 1994-2023 period, sailfish sport fishing statistics follow historic annual increasing trends in relative abundance as well as caught-and-released (i.e., positive slopes in lines shown in figure 20). Low relative abundances are observed for the years 2009 and 2010 and a very high catch rate in 2016, which appears as an anomalous billfish abundance year in the region. Average annual catch rates for the extended 1994-2023 time series resulted in 19.5 sailfish raised per trip and 9.8 caught-and-released sailfish per trip, respectively. Such averages are the highest for billfish sport fisheries anywhere in the world.

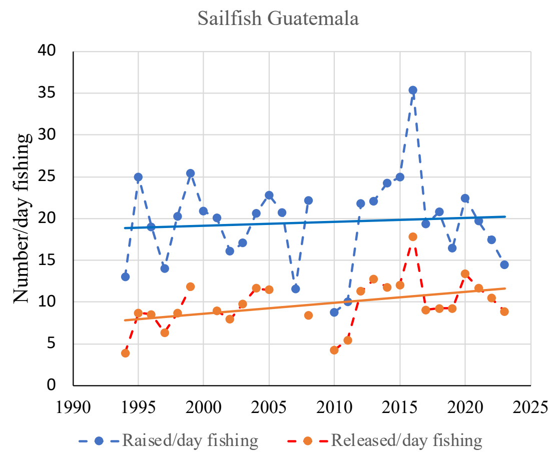


Figure 20. Sailfish annual average numbers raised per trip and numbers caught-and-released per trip in Guatemala during 1994-2023

Comparatively, catch of sailfish released per trip in Costa Rica and in Guatemala are presented in figure 21. The distributions follow apparently similar multi annual cycles. However, the trends of the two relative abundance indices are different in their direction and size scales. While the Guatemala sailfish raised per trip follows an increasing trend around the multi-year abundance cycles, the Costa Rica sailfish catch rates follow a steady trend around the similar multi-year cycle. However, a significant difference exists in that catch rates in Guatemala are about twice as large as of those observed in Costa Rica (Note scale differences in axis in figure 21). Such statistical differences may suggest that the observed trends in catch per trip may have different causes and effects. One possibility is the existence of local sport fishing exploitation that is more significant in Costa Rica than in Guatemala due to the size sport fishing fleets, as well as the large number of industrial longline fishing operations in the Economic Exclusive Zone of Costa Rica and Panama (see Fig. 28).

A possible common cause for the large multi-year cycles of relative abundance trends observed in figure 21 may be linked to possible larger regional ocean-atmosphere conditions and dynamics effecting the more coastal regions where sport fishing fleets operate. For this reason a regional Multivariate ENSO (El Niño Southern Oscillation) Index (MEI) was used as a potential driving variable responsible for the longer range cycles observed in the availability of sailfish off the coasts of Central America (Figs. 21 and 22). The cycles observed in figure 22 are very narrowly correlated in 23 out of 30 years in the data series, and especially in the last two decades.

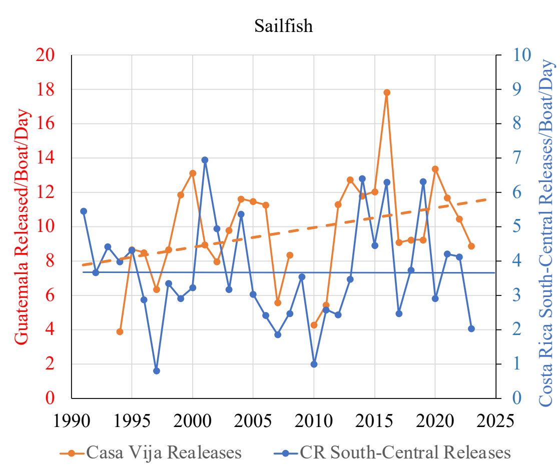


Figure 21. Sailfish caught-and-released per trip in Costa Rica and Guatemala. Note 2:1

difference in catch rate scales for each of the data sets (Ehrhardt data analyzed for this report)

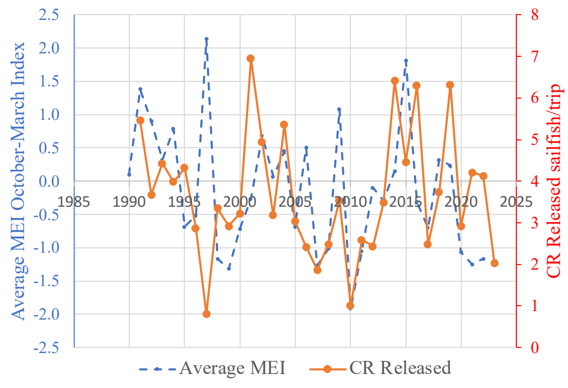


Figure 22. Distributions of Average October-March Multivariate ENSO Index (MEI) and Sailfish caught-and-released per trip in Costa Rica (Ehrhardt data analyzed for this report)

Trends in sailfish raised in Panama sport fisheries show that annual cycles appear affected by seasonal mean sea level cycles measured at Balboa, at the entrance of the Panama Canal into the Pacific Ocean (Fig. 23). Such sea level cycles are a response to the very significant changes in direction and intensity of the winds that blow in the region throughout a year, as already shown in figure 18. In general, the season of northerly intercontinental winds during December-April generate significant upwelling and decrease in sea level over the outer regions of the Gulf of Panama. Seasonal sailfish availability is important in months immediately prior and after the peak of the northerly wind events. Catch rates are very low or zero at that time most likely impacting sailfish availability to the sport fishing fleets that operate from the Darien Province in areas at the East of the upwelling regions. In figure 23 it is also observed that the trend in relative seasonal abundance of sailfish follow a very significant downward trend that reaches its lowest points during the 2012-2014 fishing seasons and then has recovered slightly from 2018 onwards.

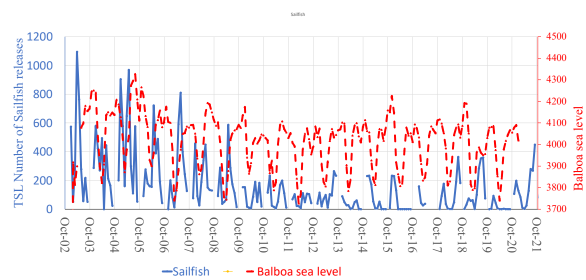


Figure 23. Historic trend of monthly accumulated cycles of sailfish released by sport fleets at Tropic Star Lodge and seasonal cycles of mean sea level at Balboa (Ehrhardt data analyzed for this report).

The annually accumulated data on the number of released sailfish per trip in Panama (Fig. 24) shows that the decrease in catch rates after 2005 is very significant showing a slightly reversing trend starting after the 2014 fishing season. In order to check if such drastic decline is local or more regional, data from sailfish landed by longline fleets from Costa Rica and reported by the Costa Rican Institute of Fisheries and Aquaculture (INCOPESCA) was used as the only source of commercial sailfish fishing statistics available in the region. The trends are coincident in that a major decline in the availability of sailfish to the commercial longline fleets of Costa Rica also started occurring after 2005 and with the same spectacular decreasing trend as the one observed in the sport fisheries of Panama.

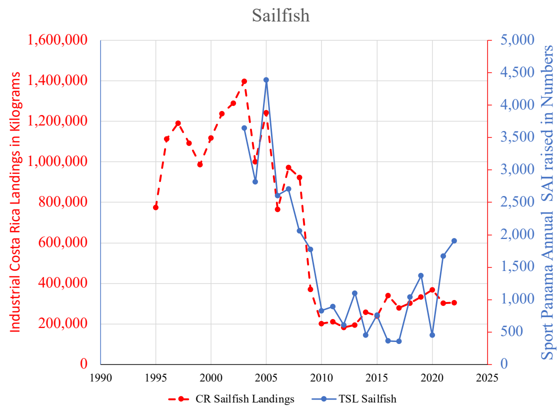


Figure 24. Matching trends but with different scales of cumulative annual relative abundance in Panama sport fisheries and annual commercially landed sailfish in Costa Rica. (Ehrhardt data analyzed for this report)

It is not known if such significant decline in sailfish production may be due to population over exploitation or a possible recruitment failure due to over exploitation of spawners or an environmental effect acting on larval and juvenile survival or a combination of all the above. As expressed by the Inter-American Tropical Tuna Commission (IATTC) Stock Assessment Group, there is a lack of population wide catch statistics that are needed for a formal statistically valid stock assessment of the status of exploitation of the sailfish population in the ETPO. Therefore, in this report only proxy statistical reasonings are used as the most plausible indirect explanations of complex interacting biophysical processes that are unobservable.

Fitchett (2015) provided an age structure of sailfish in the entire ETPO based on spatial length frequencies reported to the IATTC by tuna fishing fleets that operate in the ETPO and simulation modeling of sailfish age-at-size compositions. The global results are shown in figure 25, where ages 5 to 7 seem to predominate in the coastal regions of the ETPO. Given the apparent relative abundance of juvenile ages in the ETPO equatorial regions (dark blue and black squares in Fig. 25), Fitchett (2015) assumed that those regions may be important sailfish recruitment areas exposed to the inter annual effects of the North Equatorial Current (NEC). In fact, Fitchett (2015) found a 5-year delayed positive correlation between the intensity of the NEC and of age 5 sailfish in the biological samples. Adopting a similar reasoning but using a 3-year average NEC to control possible sources of ocean variability, and a 7-year delayed average NEC was adopted given the multi-year age classes expected in sailfish landings in the Costa Rica industrial fisheries. A plausible NEC-forced recruitment dynamic effect for the significant decrease in landings during a period when the NEC is also experiencing a significant declining trend starting in 1992 is observed in figure 26.

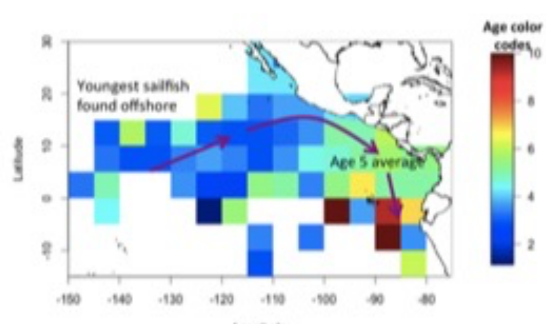


Figure 25. Spatial sailfish age distributions in the ETPO from Fitchett (2015).

The significant peak of NEC intensity in 2004-2006 may have resulted in the increased recruitment trend that led the slight recovery in sailfish landings starting 7 years later in 2013 as shown in figure 24. The number of sailfish raised in the sport fisheries of Panama, also experience a significant recovery during the period 2015-2022, but with an increased inter annual variability as observed in figure 24.

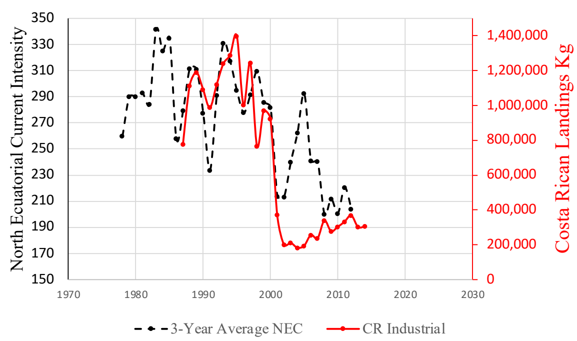


Figure 26. Historic 3-year average trend of the North Equatorial Current (NEC) and 7-year delayed annual sailfish statistical landings in Costa Rica (Note: landings are moved back 7 years from original time scale). (Ehrhardt data analyzed for this report)

The NEC intensity has been demonstrated to effect recruitment of other pelagic species in the Western and Central Pacific Ocean (e.g., Chang, et al., 2018, Zenimoto et al., 2009; Simon, et al., 2014). To check for the potentially important role and effect of the NEC on the recruitment of other billfish species in the ETPO, I used the NEC intensity index delayed 8 years to explain if a similar recruitment effected the expected multi-year age composition in blue marlin landings by longline fleets in Costa Rica. The resulting trends shown in figure 27 explain the general extended effect of inter annual variances and cycles of the NEC and the level of black marlin landings from the ETPO regions where longline fishing fleets from Costa Rica and Panama operate (Fig 28).

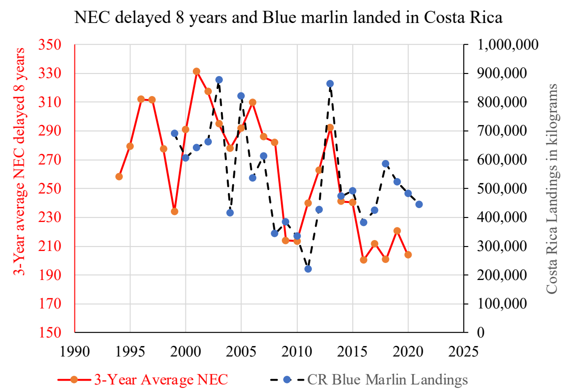


Figure 27. Historic 3-year average trend of the North Equatorial Current (NEC) and 8-year delayed annual blue marlin statistical landings in Costa Rica (Note: landings are moved back 8 years from original time scale). (Ehrhardt data analyzed for this report)

The contrasting positive trend in annual sailfish relative abundance observed in Guatemala relative to the downward trends observed in Panama sport fisheries (Fig. 23) and Costa Rica commercial landings (Fig. 24) may imply that more suitable year around habitat conditions for the sailfish should exist in the westernmost regions off the Central American marine coastal ecosystem. Analyses of the seasonal habitat compression and migrations of satellite tagged sailfish in the region off Guatemala and southern Mexico (Gulf of Tehuantepec) by the UM Billfish Research Group indicate that a semipermanent deeper (i.e., less compressed) coastal mixed layer exists in that area (Fig. 29). On the other hand, the observed billfish prey species distributing according with seasonal habitat compression dynamics in this region (Fig. 15) may be indicative of a recurring seasonal availability cycles of sailfish as an indirect function of regional wind events in Guatemala as shown in figure 16.

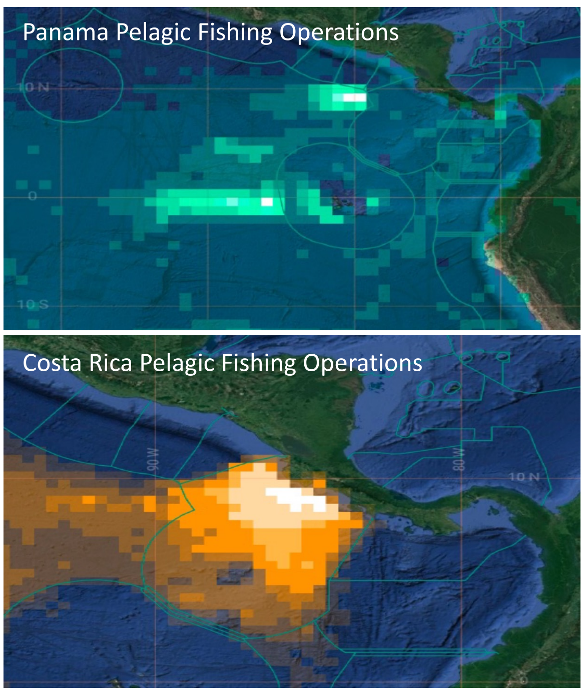


Figure 28. Spatial distribution of fishing hours deployed by pelagic fleets from Panama (Upper) and Costa Rica (Lower) https://globalfishingwatch.org/map/)

In addition, the significant spatial distribution of higher levels of dissolved oxygen off Guatemala reported by Ehrhardt et al. (2019)(Fig. 30 upper) clearly matches the preferred spatial distribution of fishing grounds of the Guatemalan sport fishing fleets (Fig. 30 lower), a condition that is only modified by the seasonal effects of the interruption of the Costa Rica Coastal Current during the prevalence of Tehuano wind events in the Gulf of Tehuantepec.

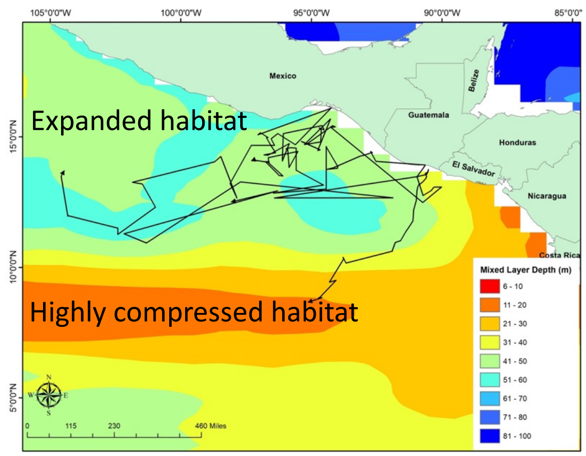


Figure 29. Color map of habitat compression and spatial distribution of satellite tagged sailfish. (Data from UM Billfish Research Group)

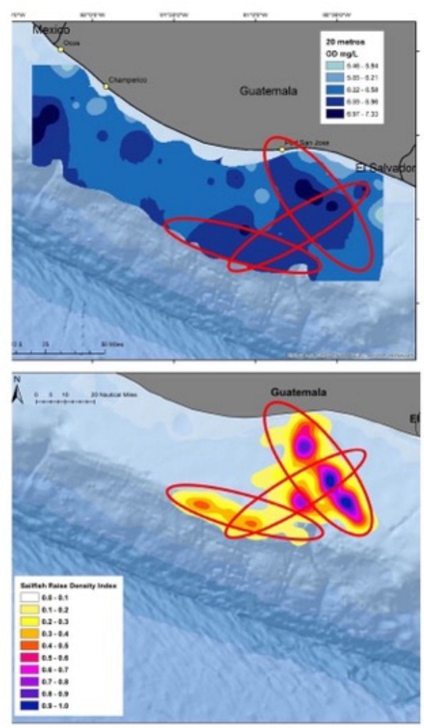


Figure 30. Spatial distribution of dissolved oxygen in the upper 20 meters layers of the ocean off Guatemala (Upper) and the spatial georeferenced areas of sport fishing operations (Lower)(Data from Ehrhardt et al., 2019 and J.E. Brown 2019)

During the period 2010-2022, sailfish caught-and-released per fishing trip in the sport fisheries of Panama, Costa Rica and Guatemala are shown in figure 31. The historic trends contrast markedly for this period in Guatemala (10.7 sailfish released per trip) relative to Costa Rica (3.9 sailfish released per trip) and Panama (0.90 sailfish released per trip). Such differences may be assumed to be a response of sailfish inhabiting a seasonally more suitable habitat off the coasts of Guatemala and southern Mexico (Figs. 15 and 29).

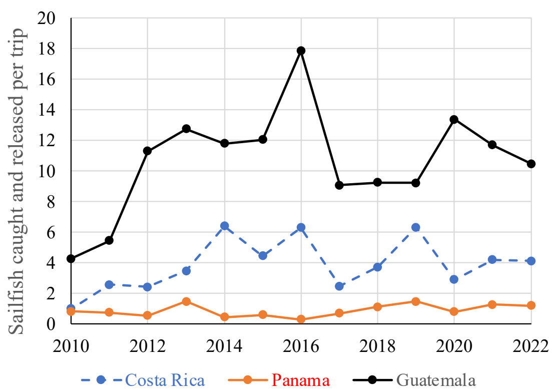


Figure 31. Average annual 2010-2022 distribution of caught-and-released sailfish in Panama, Costa Rica and Panama. (Ehrhardt data analyzed for this report)

Conclusions

The significant vertical habitat compression due to hypoxia (Fig. 10) and the regional seasonal horizontal stratifications resulting from three strong seasonal upwellings in the ETPO (Fig. 13), appear to influence the availability and catchability of the billfish in regions off Central America and Panama. Variability and trends of annual catch rates in the sport fisheries in the ETPO could also be related to population dynamic events that should be functionally related to biological recruitment abundance of the billfish species (Figs. 26 and 27). Reproductive success in egg broadcasting marine organisms, such as billfish species, depends on two fundamental population biology conditions, first, the fecundity achieved by the number of females and males available for spawning after exploitation and, secondly, on the survivorship of the eggs, larval and juvenile stages until adulthood. The billfish early life stages are impossible to assess at the population level while the survivorship to adulthood may be inferred through statistical observations of the adult abundance that appear as catch in the fisheries. Recruitment success is very often correlated to environmental factors that most likely affect development and survival of the early life stages. In the case of sailfish and black marlin in the ETPO we found that the North Equatorial Current (NEC) has inter-annual cycles and variances in intensity that match very closely the variances and cycles observed in the commercial landings of the two billfish species in the pelagic commercial fisheries of Costa Rica. There are other fisheries in the Equatorial Western Pacific where recruitment of pelagic species is also correlated very closely with NEC inter annual intensity trends that may provide support for the use of such ocean current as a forcing billfish recruitment index in the

ETPO. Likewise, it is observed that important decreasing trends in some of the coastal sailfish sport fishing catch rates may be the result of high levels of fishing intensity in tuna and mahi-mahi fishery exploitation in the ETPO where billfish are caught as by-catch (Figs. 5 and 28).

In Guatemala, both the number of sailfish caught per fishing trip and those caught and released per fishing trip follow historically increasing trends over the past 30 years (Fig. 20 and 31). During that period spectacular numbers of sailfish were raised per day fishing averaging 19 to 20 while numbers of sailfish caught-and-released are about an average of 10 per trip. This is in contrast to the significant decreases in total cumulative sailfish caught-and-released reported for Panama where average annual catch rates of less that 1 sailfish per day fishing are observed after 2010 (Fig. 31). In Costa Rica a very significant multi-year cycle is observed in sailfish caught-and-released in sport fisheries. The difference in magnitude of the observed trend in Costa Rica relative to catch rates in Guatemala may be an indication of important fishing intensities exerted by large sport fishing and commercial fishing fleets observed in the area.

The drastic decreases observed in landings of sailfish caught by Costa Rican longline fleets operating in the Central Pacific Ocean and those experienced in sport fisheries in the easternmost region in the Gulf of Panama (Fig. 24) appear to be linked to decreases in sailfish recruitment rates as a result in part of the reported weakening of the equatorial upwelling and equatorial current systems predicted by the IPSL model used by Lehodey et al. (2010, 2012, 2013 and 2014), conditions that are also observed in the decreasing trend in the intensity of the North Equatorial Current data used here after 2006 (Fig. 27).

The summarized integrated findings of ecosystem based billfish research in the ETPO presented in this report indicate that billfish resources available to sport fishing has declined considerably in the eastern most regions of the ETPO off Central America and Panama, while still contains a significant availability of the species off Guatemala and southern Mexico (i.e., off the State of Oaxaca). This condition appears to be a response of sailfish stocks to accumulate in a localized less compressed ecosystem in that area. It is of importance to note the downwelling region that forms to the north of the Gulf of Tehuantepec during the seasonal Tehuano wind events (Fig. 14). Downwelling processes are characterized by accumulation of food at the surface available to more localized marine food chains. Such conditions appear to attract tunas and other larger pelagic species as demonstrated by the spatial distribution of tuna fishing effort in a region just north of the Gulf of Tehuantepec (Fig. 32) and of sailfish caught as bycatch by such fleets in the same area. To the East of the Gulf of Tehuantepec, there is a region characterized by upwelling generated by the Tehuano wind events (Fig. 14). Upwellings increase nutrients enhancing ocean production of chlorophyll; therefore, supporting a food chain for the small pelagic species that are important as billfish prey (Fig. 33). In figure 33 it is indicated in red the geographical position of Guatemala sport fishing vessels in close association to the chlorophyll concentrations generated from seasonal upwelling.

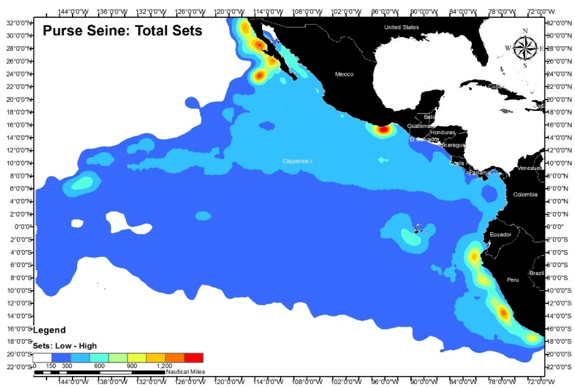
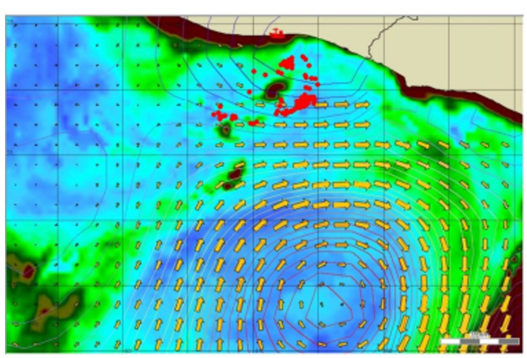


Figure 32. Regional historic distribution of purse seine sets in the ETPO indicating a hotspot with increased deployment of fishing effort to the west of the Tehuantepec Gulf in southern Mexico (Data from IATTC)



Source: UM PhD Dissertation
M. D. Fitchett

Figure 33. Geostrophic circulation and chlorophyll concentrations to the southeast of the Gulf of Tehuantepec, off the coast of Guatemala. Red spot indicate position of sport fishing vessels from Guatemala.

Therefore, the marked differences observed in sailfish availability among the sport fisheries of Guatemala, Costa Rica and Panama may be the result of differences in regional population abundance and density mediated by significantly different permanent as well as seasonal ocean/atmospheric events forcing physical and biological mechanisms that appear to play a major role in structuring coastal marine ecosystems in the ETPO. The dissimilar spatial exploitation effects from commercial and sport fisheries should also effect the temporal availability of the sailfish; therefore, reflected in the sport fishing outcomes.

Lack of comprehensive ecosystem research on the impact of longline fisheries on billfish stocks and the effects of potential overcapacity in some regional sport fisheries may be important points that merit more attention from those persons and institutions interested on the long range sustainability and utilization of billfish as iconic species in the World oceans.

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