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Cover Page Footnote

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Atlantic Sailfish (*Istiophorus albicans*) Distribution off the East Coast of Florida from 2003 to 2018 in Response to Sea Surface Temperature

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Abstract

The Atlantic sailfish (*Istiophorus albicans*) ranges from 40°N to 40°S in the Western Atlantic Ocean and has great economic and recreational value for sport fishers. Off the east coast of Florida, recreational fishing boats often target this species due to its size, speed, and strength. This project aimed to determine the relationship between sea surface temperature (SST) and the distribution of Atlantic sailfish caught and released over a fifteen-year period (2003 to 2018). Tagging information was collected from The Billfish Foundation and NOAA who have the most extensive programs for billfish. Using the time and location of each reported sailfish, a satellite-derived SST value was obtained for each point. The purpose of this study was to determine if sea surface warming was associated with changes in sailfish distribution. On average, sailfish were caught at 26.16 ± 1.70°C ($\bar{x}$ ± s.d.) over the fifteen-year period. The most sailfish catches occurred at temperatures ranging from 25.2°C to 25.5°C. Over the fifteen-year period sailfish catches decreased at lower temperatures (23°C and 24°C) and at 31°C. At 25°C and 30°C there was no change in catch numbers of sailfish. From 26°C to 29°C there was an increase in the number of sailfish. Based on these results, increasing ocean temperatures will have an impact on distribution and habitat utilization of sailfish. Warming sea surface temperatures create a need for more policy and regulation to protect the Atlantic sailfish and related highly migratory billfish species.

Keywords: sailfish, billfish, sea surface temperature, sst, climate change, recreational fishing, tagging

Introduction

Sailfish, *Istiophorus*, are an epipelagic billfish species and occupy the Atlantic and Indo-Pacific as two different species— the Atlantic sailfish, *Istiophorus albicans,* and the Indo-Pacific sailfish, *Istiophorus platypterus.* Sailfish prefer to stay near the surface waters and stay in these areas substantially more than other billfish species such as marlin and swordfish making them an easily targeted species to catch recreationally. Sailfish spend 75.7% of their total time during the day in surface waters (above 20 meters), but at night spend only 46.7% of their time there (Kerstetter, Bayse, Fenton, & Graves, 2011). These fish make some deep dives to approximately 50 meters to 150 meters, presumably to feed (Kerstetter et al., 2011). In another study, it was found that sailfish spend 84.3% of their time above a 10-meter depth as well (Hoolihan, 2005).

In addition to depth, sailfish prefer to inhabit certain temperature ranges. One study found that sailfish occupy a median temperature of 26.4°C (Lam, Galuardi, Mendillo, Chandler, & Lutcavage, 2016). In another study, sailfish were found in an overall range of 20°C to 26° C and in the subset range of 22°C to 26°C, 70.8% of the fish occupied the 24°C to 25°C temperatures (Hoolihan, 2005). In the southern Gulf of Mexico and Florida straits, 89.6% of sailfish spent their time in a temperature range of 25°C to 29°C with some occupying 30°C and above (Kerstetter, Bayse, Fenton, & Graves, 2011). Due to this ideal temperature range, sailfish exhibit migratory behavior according to seasons and most catches occur between late fall and early spring (Orbesen, Hoolihan, Serafy, Snodgrass, Peel, & Prince, 2008).

Temperature plays an important role in the habitat selection of sailfish and other highly migratory species, resulting in increasing sea surface temperatures (SST) affecting these fish in many ways. Temperature changes can impact the population dynamics of these species, resulting in possible loss of breeding habitats, longer migratory pathways, mismatch in timing when moving or reproducing, and changes in prey availability (Robinson, Learmonth, Hutson, Macleod, Sparks, Leech, … & Crick, 2005). Changes in water temperature, such as above 28°C to 30°C, can affect the survival of the fish as well as their larvae and eggs, which can lead to changes in the distribution of species as well as different habitat utilization (Dell'Apa, Carney, Davenport, & Carle. 2018). Results of climate modeling indicated a recent increase in temperature and that by 2090 there will be a 39-61% decrease of bluefin tuna larval occurrence. This increase in temperature will also shift the suitable habitat for the bluefin tuna larvae by 2050 and may lead to earlier spawning (Dell'Apa et al., 2018). A similar pattern may occur for sailfish due to their biological similarities as well as their similar habitat and distribution in surface waters. This will affect the population dynamics of sailfish, as well as other species that are dependent on or affected by them. The possibility of far-reaching consequences as a result of temperature fluctuation is why it is important to study how environmental factors can affect these fish.

Due to an increase in SST, food may not be as readily available for larger species like sailfish. This may result in fish moving to other areas in order to find food, which could then affect larval survival rates depending on the areas that the fish move to due to sailfish larvae preferring temperatures around 28°C (Mourato, Hazin, Wor, Travassos, Arfelli, Amorim, & Hazin, 2010). An increase in temperature often causes a decrease in dissolved oxygen in the ocean as well. This may result in the expansion of the oxygen minimum zone, which has been seen in the tropical northeast Atlantic Ocean (Stramma, Prince, Schmidtko, Luo, Hoolihan, Visbeck, … & Körtzinger, 2012). A decreased level of dissolved oxygen can influence the habitat of sailfish to an even narrower surface layer and due to their highly active lifestyle requiring oxygen for metabolic processes, without access to enough dissolved oxygen will decrease sailfish density. Forcing sailfish into these narrower surface layers increases the chance of them being caught by commercial fisheries (Stramma et al., 2012). It has already been projected that 90% of the ocean's large predatory fish could have been lost due to fishing and this narrower range near the surface makes these large fish even more vulnerable (Myers & Worm, 2003).

Due to the vulnerability of highly migratory species and their importance in maintaining healthy population dynamics in the pelagic community, conservation is crucial. Policy can be created to ensure that management of these species is maintained and that anthropogenic and environmental impacts will not harm these important predators. Some regulations have been enacted such as the Magnuson-Stevens Fishery Conservation and Management Act in 1976 which governs marine fisheries in U.S. waters and the Billfish Conservation Act in 2012 which prohibits the sale of billfish or billfish products. More needs to be known about these fish, particularly about the relationship between SST and their movements, to create policy that can benefit them. This study was done to learn more about temperature and sailfish to determine if sea surface temperature affects sailfish distribution in the Atlantic off of the east coast of Florida from the Keys to the Jacksonville area. This was done by using sailfish tag data from The Billfish Foundation (TBF) and NOAA from the years 2003 to 2018 to give a fifteen-year timeframe. SST data from NASA Ocean Color was then used to correlate a temperature value with each sailfish landed and analysis was done. The main purpose of this study was to determine if the slightly increasing temperatures that have occurred would affect the sailfish distribution.

Materials and Methods

Sailfish were caught, tagged with streamer "spaghetti" tags, and released by anglers off the east coast of Florida (The Keys to Jacksonville) from years 2003 to 2018. Tag information was written down on a tag data report card, which includes the ID tag number, date caught and released, species, condition of the fish, weight and length if possible, locality, latitude and longitude, and any other notes. This information was reported back to The Billfish Foundation to be entered into the tagging database for billfish. A similar process was used to retrieve the tag data from NOAA. Error could have occurred when collecting this specific data such as wrong latitude and longitude measures which should be taken into consideration. From the data obtained over this fifteen-year period, 7860 sailfish were used in this study.

The sailfish tag data including latitude and longitude and date of catch and release was input into ArcGIS Pro along with satellite-derived sea surface temperature layers from NASA Ocean Color. The tag data was categorized for each month of every year from 2003 to 2018. The tag information was then joined to the sea surface layers for each month of each year, giving each landed sailfish an SST value. This process was consistently for each sailfish out of the 7860 total fish used in this study. With each sailfish caught having an SST value, the information was exported into a data analysis program.

Histograms of the number of sailfish caught compared to the sea surface temperature were created as well as linear regressions for the number of sailfish caught at specific temperatures from 2003 to 2018. In addition, the seasonality of when anglers catch sailfish need to be accounted for because this analysis only provides the sailfish *caught*, not the overall population that may exist and may be affected by SST. There were not any control subjects in this study.

Results

Table 1. Number of Sailfish Caught According to Sea Surface Temperature from 2003 to 2018	
Sailfish Caught	SST (°C)
1	19
2	20
3	21
46	22
148	23
795	24
2067	25
2116	26
1167	27
622	28
551	29
203	30
127	31
10	32
2	33
Mean Temperature ($\pm$SD)	26.16 ± 1.70

Table 1. Number of Sailfish Caught According to Sea Surface Temperature from 2003 to 2018. Displays numbers of sailfish caught/released from sea surface temperatures 19°C to 33°C as well as the mean temperature that sailfish were caught at.

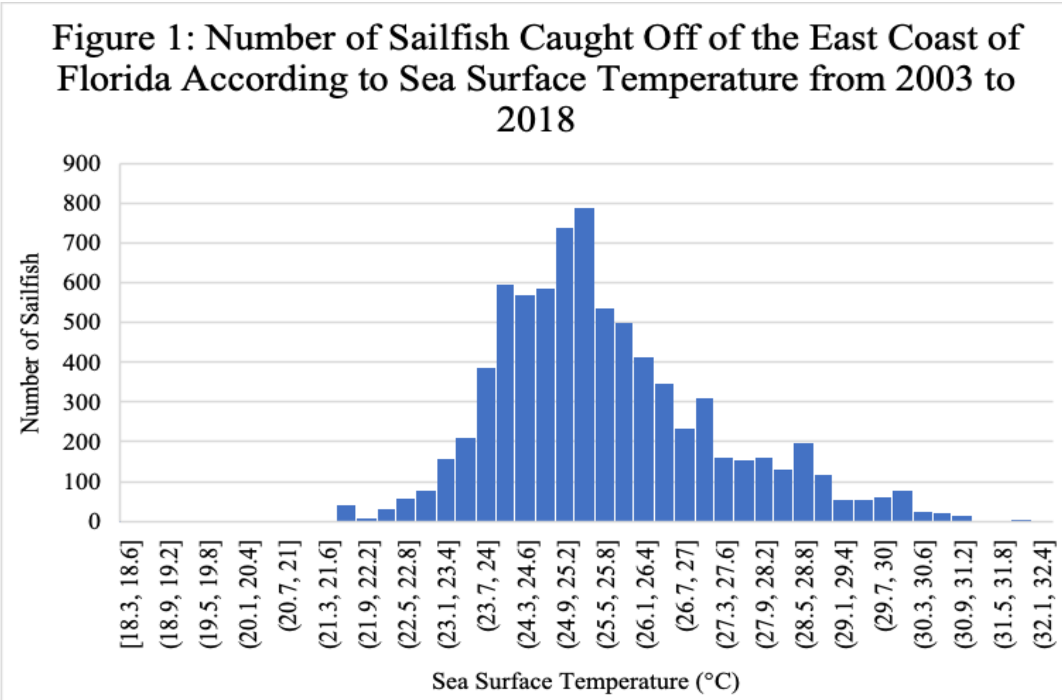

Figure 1. Number of Sailfish Caught Off of the East Coast of Florida According to Sea Surface Temperature from 2003 to 2018. Histogram displays the number of sailfish caught at specific sea surface temperatures over a fifteen-year period.

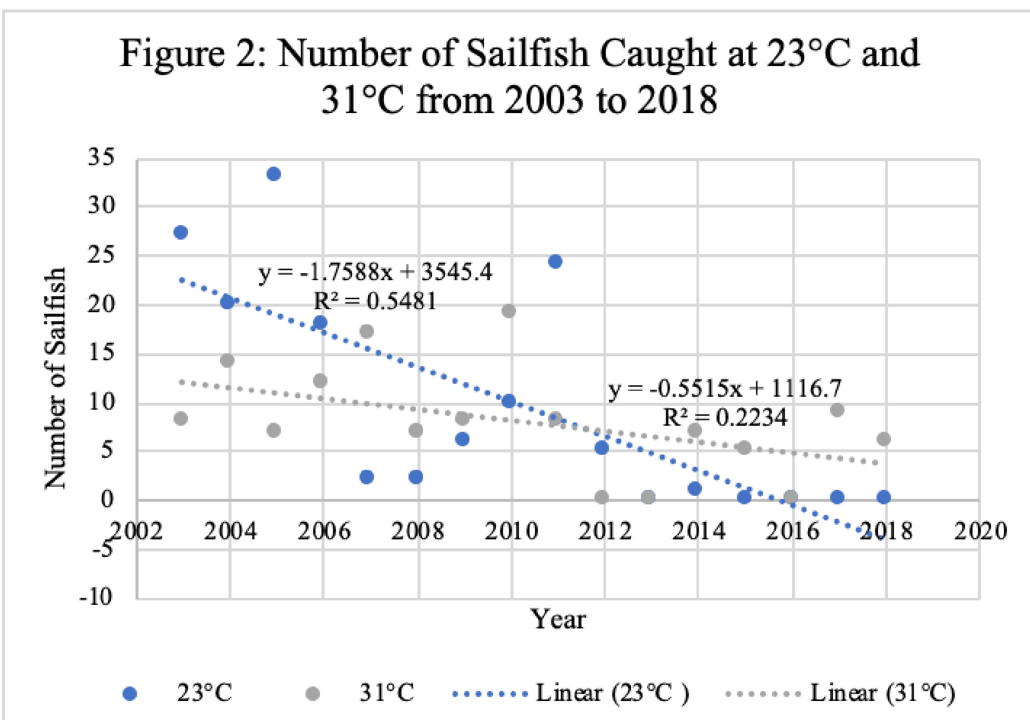

Figure 2. Number of Sailfish Caught at 23°C and 31°C from 2003 to 2018. Linear regression shows the number of sailfish caught at 23°C and 31°C over a fifteen-year period showing a decrease in catches at these two temperatures.

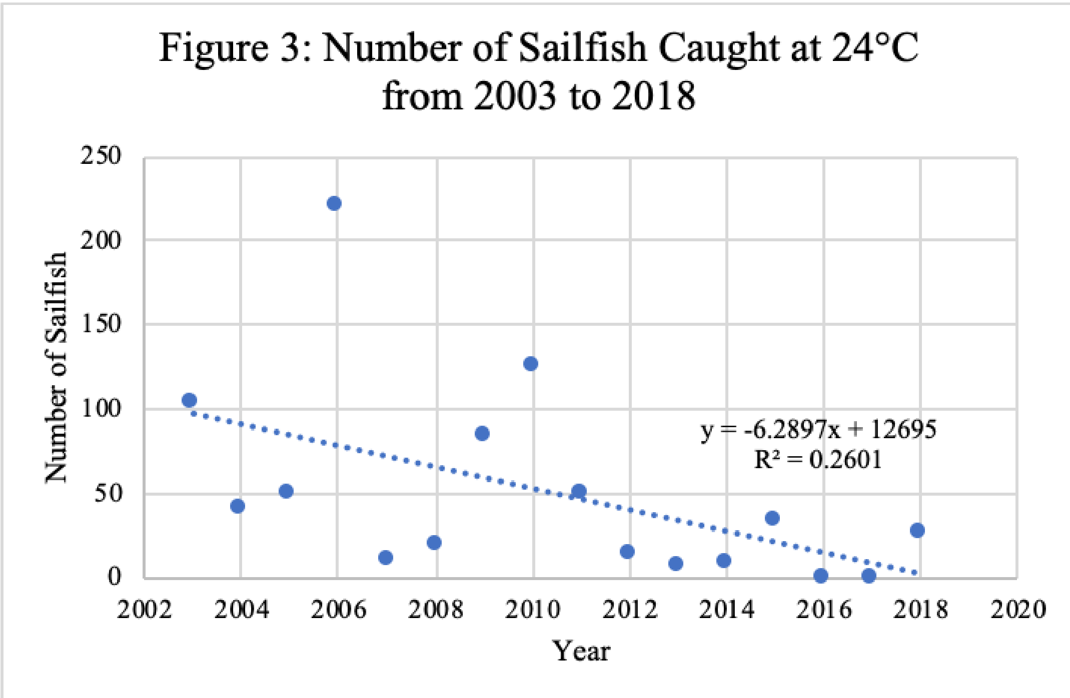

Figure 3. Number of Sailfish Caught at 24°C from 2003 to 2018. Linear regression shows the number of sailfish caught at 24°C over a fifteen-year period showing a decrease in catches at 24°C.

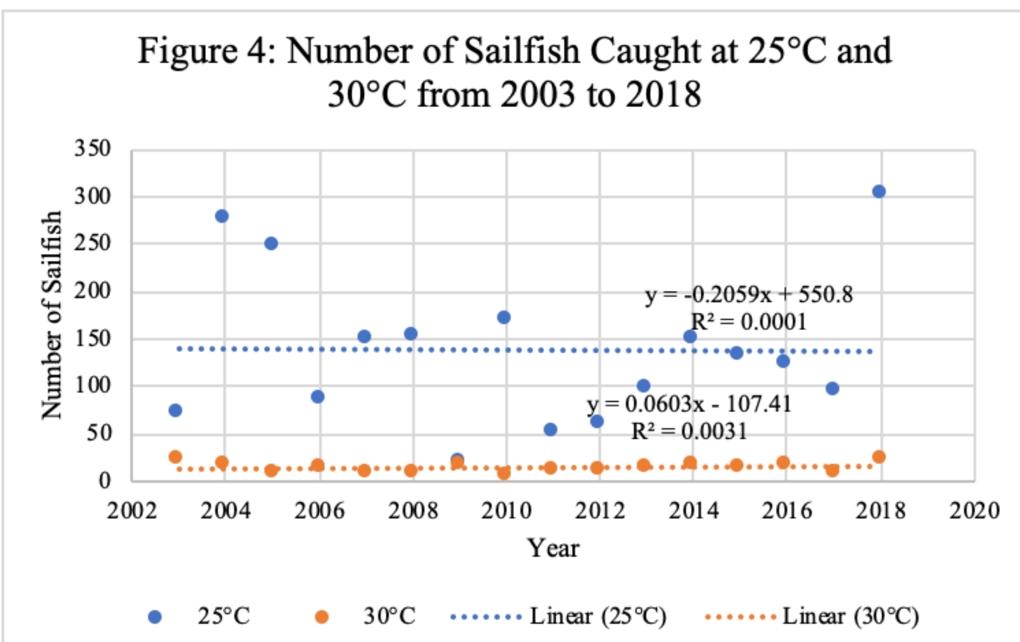

Figure 4. Number of Sailfish Caught at 25°C and 30°C from 2003 to 2018. Linear regression shows the number of sailfish caught at 25°C and 30°C over a fifteen-year period showing a constant number of catches at these two temperatures over time.

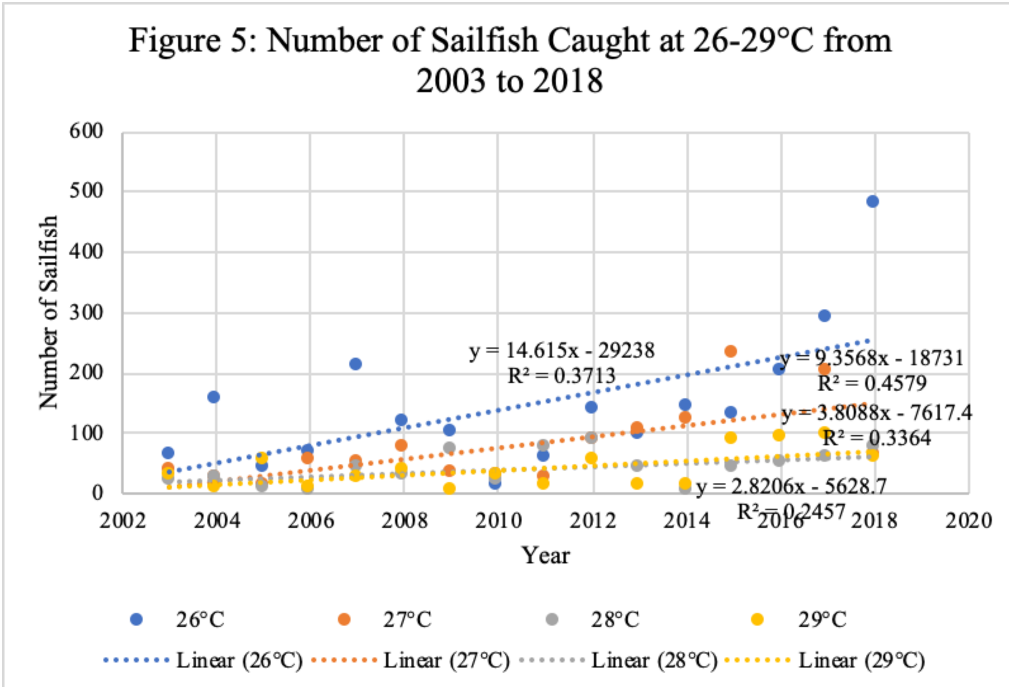

Figure 5. Number of Sailfish Caught at 26-29°C from 2003 to 2018. Linear regression shows the number of sailfish caught at 26°C, 27°C, 28°C, and 29°C over a fifteen-year period showing an increase in catches at these temperatures over time.

These results indicate that the mean temperature that sailfish were caught at from 2003 to 2018 off the East Coast of Florida in the Atlantic was 26.16 ± 1.70°C ($\bar{x}$ ± SD.) indicating that most of the values, sailfish catches, lie close to the 26.16°C mean temperature (Table 1). Figure 1 displays that the most landings of sailfish occurred at the temperature of 25°C particularly 25.2-25.5°C.

Figures 2 through 5 display the number of sailfish caught off the east coast of Florida in the Atlantic at particular temperatures from 2003 to 2018. Figure 2 shows that at 23°C and 31°C that the rate of catches at these temperatures decreased from 2003 to 2018 with R^2 values of 0.5481 and 0.2234. Figure 3 displays a similar relationship to Figure 2, that landings at 24°C have decreased over time as well (R^2 of 0.2601). Figure 4 shows a linear relationship at 25°C (R^2 value of 0.0001) and 30°C (R^2 of 0.0031) showing that there was a constant number of catches at these temperatures over the fifteen-year period. Figure 5 shows the catches of sailfish at 26°C (R^2 of 0.3713), 27°C (R^2 of 0.4579), 28°C (R^2 of 0.2457), and 29°C (R^2 of 0.3364) and that there was an increase in landings at these temperatures.

Discussion

The average temperature that sailfish were caught at was 26.16°C ± 1.70°C ($\bar{x}$ ± s.d.) (Table 1). This corresponds with other literature found that sailfish occupy a median temperature of 26.4°C (Lam et al., 2016). Figure 1 displays that most of the catches occurred at 25.2-25.5°C similar to other literature that states in a range of 22°C to 26°C, that 70.8% of sailfish occupied the 24°C to 25°C temperatures (Hoolihan, 2005).

Over time, the distribution of sailfish caught has changed in regard to different sea surface temperatures. This study found that from 23°C to 24°C, there has been a decrease in sailfish landed from 2003 to 2018 at these two temperatures (Figure 2 and Figure 3). This may be due to sea surface temperatures changing. There may not be many areas in the surface waters that are lower temperatures such as 23°C and 24°C in the later years of this fifteen-year study compared to the beginning of the study in 2003 because of surface waters warming. At 25°C, there is a linear relationship between year and catches showing that there has been the same number of sailfish catches from 2003 to 2018 indicating 25°C is a comfortable and preferable temperature for sailfish off the east coast of Florida (Figure 4). This is once again supported in other studies, which have indicated that sailfish like to occupy waters in the temperature range of 24-25°C (Hoolihan, 2005). From 26°C to 29°C there is an increase in sailfish landings, indicating that these fish are inhabiting warmer waters as well (Figure 6). This is mirrored in a more recent study from 2010, where sailfish were found to spend the majority of their time within the temperatures 26-28°C (Mourato, Carvalho, Hazin, Pacheco, Hazin, Travassos, & Amorim, 2010). This increase over time shows that fish in the earlier years of the fifteen-year sample period were not occupying these warmer waters as much as they are now. This could be due to the increase in sea surface temperature, as sailfish are moving to occupy their preferred thermal environment, which then affects the range that they are found in (Robinson, Hobday, Possingham, & Richardson, 2015).

In addition to changes in sailfish movements in regard to SST, this temperature change can result in the loss of breeding grounds, longer migratory routes, a delay in migrating or reproduction, and changes in prey availability (Robinson et al., 2005). With reproduction, it is found that larval sailfish like to occupy warmer waters than adult sailfish, occupying temperatures greater than 28°C (Mourato, Hazin, Wor, Travassos, Arfelli, Amorim, & Hazin, 2010). However, as the SST continues rising for the foreseeable future, potentially past this optimal 28°C temperature point, larval survival could be diminished, as seen in the model for bluefin tuna (Dell'Apa et al., 2018).

The number of sailfish caught at 30°C has not changed from 2003 to 2018 (Figure 4). This corresponds with other studies where it was found that some sailfish occupied this 30°C temperature mark (Kerstetter, Bayse, Fenton, & Graves, 2011). At 31°C, there is a decrease in sailfish catches over time (Figure 2). This is interesting because from the range of 26°C to 29°C, there is an increase in sailfish landings. It is possible that this downward change in trend could be due to not having a large enough sample size of sailfish. These higher temperatures usually occur during the summer season, which is not during the sailfish sportfishing season, mid-November to early March, in Florida. This needs to be accounted for because this data is a representation of the fish caught and released, not the population of sailfish as a whole. At these two temperatures, not a lot of sailfish were caught, so more tagging information would be needed to determine if the trend seen is due to lower sailfish densities or simply lower fishing effort. Since sailfish tend to spend their time in waters with a preferable temperature range, these fish can have up to an 8°C change of this range and these higher temperatures may be on the cusp of this preferable range (Mourato, Carvalho, Musyl, Amorim, Pacheco, Hazin, & Hazin, 2014).

It has been seen recently that the seasonality of certain billfish species such as sailfish has shifted. Local fishermen who fish off the east coast of Florida have said that their seasons for fishing have been pushed back further into the year. This could be potentially due to the rising temperatures, changing the best time to fish for these highly migratory species to later when it is cooler. It was discussed that when cold fronts come through Florida, they have a beneficial effect on catching sailfish and that more fish are caught when the temperature is cooler. If it is hot and no cold fronts occur, then the sailfish typically push through the area in only two to three days, whereas if it is colder there will be more bites for a longer period of time. From talking to locals about their experience, they explained that the seasonality of sailfish depends highly on the temperature, particularly colder temperatures caused by cold fronts.

Further research has shown that each season's catch ratio for certain migratory species has changed in regard to increasing SST (Ho, Lu, He, Lan, & Chen, 2016). For the spring and summer, where there was increasing SST there was an increased number of fish caught (Ho et al., 2016). Not only has there been an increase in landings during spring and summer, but these catches have increased rapidly since 1997 (Ho et al., 2016). In comparison, it was seen that the number of catches was inhibited for the fish that had winter seasonality (Ho et al., 2016). This study indicated that the increase in sea surface temperature has caused changes in fishing seasons due to these seasonal migratory fish moving towards cooler waters. This is similar to what has been seen off the east coast of Florida—the best time to catch sailfish used to be in the early winter months, however, due to the increase in SST this time has shifted due to a decrease in fish during the winter months. Because of this, fishing effort has shifted as well due to this change in seasonality (Guiet, Galbraith, Kroodsma, & Worm, 2019).

Based on these results, increasing ocean temperatures will have an impact on the distribution and habitat utilization of sailfish. This is seen in the increase or decrease of catches at certain temperatures over time. These results indicate that these fish are being caught more in warmer waters than in previous years possibly due to the increasing SST related to climate change. These findings can be justified due to the large sample size, 7860, used as well as the results corresponding with other literature and studies. This study used more individual fish than others, however, less specific data was obtained from each fish wherein other studies more information on each specific fish was found by using satellite tags.

With this study, there were some limitations. Firstly, streamer “spaghetti” tags were used so the only information gathered from the fish was data recorded from the angler that landed the sailfish. Depth, exact temperature, light levels, and direct movements were not accessible in this study due to not having access to more advanced tags such as satellite tags. Future studies can use satellite tags to gather a better representation of the movements and temperatures that sailfish occupy. Secondly, the seasonality of when anglers caught the sailfish need to be accounted for. This study only provides information on sailfish *caught*, not the overall population that may exist and be affected by SST. And thirdly, the downward trend that was seen at 31°C may have been due to not having a large enough sample size of sailfish landed at this temperature. These higher temperatures typically occur during the summer season which is not during the sailfish sportfishing season in Florida. With the limitations provided, it would be useful to have more specific tagging data of sailfish to get a better representation of where these fish move in regard to SST, and this can be accomplished by using satellite tags. This study provides a good preliminary approach and satellite tags can be used to obtain more specific data in the future. It would also be beneficial to have tags that were not just deployed in the more common sportfishing seasons since sports fishermen did tag the sailfish utilized in this study. More research needs to be done to discern why sailfish prefer certain temperatures and a study on food availability of sailfish could be conducted to determine if prey availability determines why these fish move from one area to another in regard to temperature.

Conclusion

This study aimed to determine if the distribution of Atlantic sailfish would be altered due to changes in sea surface temperature off the east coast of Florida from 2003 to 2018. It was found that the average temperature that the most sailfish were caught at was 26.16°C, giving a preferred or optimal temperature for these sailfish off the coast of Florida. It was also found that sailfish were landed at an abundance of different temperatures over the years in the fifteen-year study. At 23°C and 24°C, sailfish were caught earlier in the study, near 2003 as compared to 2018, showing a decrease in landings at these temperatures over time. Sailfish caught at 25°C stayed consistent over the fifteen-year time frame, however, from 26°C to 29°C there was an increase in catches of sailfish over the 15 years. At 30°C there was a constant amount of sailfish caught and at 31°C there was a decrease in sailfish over time, possibly due to not having a large enough sample size at these temperatures. These are pretty warm waters and it is uncommon for anglers to fish at these higher temperatures due to their experience-based understanding of when the best time to fish for sailfish is. These results are important because they provide evidence that increasing ocean temperatures will impact the distribution and habitat utilization of sailfish. These studies provide information for the conservation of sailfish, billfish, and other highly migratory species that may be affected by anthropogenic temperature changes. With this information, policy can be created to help maintain these species. Because of the increase in catches at increasing temperatures, it is important to monitor this so that overfishing does not occur.

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