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Research Article

Against Common Assumptions, the World's Shark Bite Rates Are Decreasing

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The trends of the world's top ten countries relating to shark bite rates, defined as the ratio of the annual number of shark bites of a country and its resident human population, were analyzed for the period 2000-2016. A nonparametric permutation-based methodology was used to determine whether the slope of the regression line of a country remained constant over time or whether so-called joinpoints, a core feature of the statistical software *Joinpoint*, occurred, at which the slope changes and a better fit could be obtained by applying a straight-line model. More than 90% of all shark bite incidents occurred along the US, Australia, South Africa, and New Zealand coasts. Since three of these coasts showed a negative trend when transformed into bite rates, the overall global trend is decreasing. Potential reasons for this decrease in shark bite rates—besides an increase in the world's human population, resulting in more beach going people, and a decrease of sharks due to overfishing—are discussed.

1. Introduction

Sharks are at the top of most people's minds when entering the sea, for seemingly good reasons, considering the still prevalent shark hype stemming from news outlets around the world [1–3]. But the media is not the only source of erroneous shark bite lore [4]. Some of the experts, too, got carried away in the past when elaborating on this phenomenon [5–8]. The overall consensus is that shark bites are on the rise despite that the yearly bite counts range between eighty to a hundred incidents [9–12]. Considering that sharks still represent the most abundant top predators weighing over 50 kg on our planet and that millions of people swim in the seas each day, this yearly bite count remains extremely low when compared to other predators commonly involved in human incidents [13–16]. However, an even more surprising fact about bite count predictions is that the beach visiting populations directly affecting the bite numbers are regularly excluded from predicting long-term tendencies [9]. Such an approach is fallacious because the number of people bitten by sharks directly corresponds to the number of people entering the sea. Hence, trends and predictions must include the respective human population. To that extent, we introduced bite rates [13–16]: the ratio of annually reported shark bites for a given region to the annual estimated beach attendance for that region. The assumption is made that an equal number of these people, at some point, will enter the sea. Since beach attendance populations are not always determined, any population number that can be recognized as akin to the number of people attending a beach can be used as a valid substitute. Therefore, the regional, state, or country populace can be utilized as such a proxy [16].

By creating regression models—using the software package Joinpoint—to analyze the bite rate trends for the top ten countries from 2000 to 2016, we can determine if statistically significant changes in these trends have occurred. A model for the global bite rates was also created to determine the accuracy of the chosen method by predicting the bite rates for 2018 and comparing this number with the actual incident number of that year.

2. Methods

The number of bites for 2000-2016 for the world's top ten countries was drawn from the "Global Shark Attack File" incident dataset of the Shark Research Institute [17], which lists every encounter that ends in a human injury or damages a surfboard, boat, and so on. Due to the vast variety of what is labeled an "attack," some of these incidents reflect biased occurrences, thus falsifying the trends, and so they were excluded from this study. Such incidents entailed spearfishing, surf and shark fishing, or shark feeding. Furthermore, all bumps into persons that did not render a wound or lacked any physical evidence of teeth marks on surfboards, kayaks, or boats were also excluded. Additionally, throughout the period, there were also a series of questionable deaths that were likely drowning incidents with later scavenging by sharks [18–20].

2.1. Replacing Bite Counts with Bite Rates. To determine the bite trends for the top ten countries, we used bite rates instead of bite counts [13–15]. A bite rate is defined as the ratio of the annual bite count for a specified region to the corresponding beach going population or any related proxy [13–15]. Here, we used the population numbers of the respective countries to determine the rates.

2.2. Incident Modeling through Time. We decided to employ the software *Joinpoint* 4.6.0.0 because it uses a modern nonparametric permutation-based methodology to test whether the slope of a regression line remains constant over time or whether there are so-called joinpoints at which the slope changes and a straight-line model then obtains a better fit. Such a regression test is used by the National Cancer Institute (NCI) to monitor cancer rates over time. We are using this modern epidemiology-based approach to benefit from the latest developments in this field.

In order to decide whether it is better to use a fixed slope linear model, we used the permutation method in which we randomly permuted residuals from the straight-line model, meaning we shuffled around the distances between the regression line and each observation [21]. We then calculated the test statistic T for the permutation dataset and measured how much evidence the data provides against the null hypothesis by estimating the proportion of the permutation datasets. The corresponding T values are at least as extreme as the one we observed with the original dataset. If the tests were significant, then at least one joinpoint existed at which the true slope has changed. Joinpoints can range from none to several within a single regression.

2.3. Regression Models Used. Since the above-mentioned analysis did not reveal any joinpoints for any country, a fixed slope linear model

$$y_i = a + bx_i \quad (1)$$

for the different countries was used where y_i stands for the bite counts in year i, x_i stands for the year i, a stands for the regression intercept, and b stands for the slope of the regression line.

Although this simple linear regression model was sufficient for the individual countries, it was not adequate to measure the global trend, including predicting the number of bites for 2018. While individual countries show some regularity when it comes to bites, global bites rather fluctuate due to the occasional freak incidents in countries where bites are normally rare or even previously nonexistent. This variation made the simple linear regression model insufficient, and a better fit was needed. The best outcome was reached by transforming the bite counts to their natural log, and dividing these values by the respective population counts. Thus, a new response variable was proposed, following the new model:

$$\frac{\ln(y_i)}{\text{population}} = a + bx_i \quad (2)$$

where ln stands for the natural log function and a and b stand for the (new) intercept and slope, respectively.

In order to predict the bite count for 2018, we obtained the predicted value of the natural log of the bite counts, divided by the matching population count, and retransformed the said value to the original unit for bite counts. For the prediction to obtain the intercept and slope, we used the regression procedure *proc reg* from the Statistical Analysis System (SAS).

During the remainder of the paper, we will refer to the ten countries with the most shark bites as merely the "top ten countries."

3. Results

The project aimed to determine if the shark bite numbers for the top ten countries were on the increase or not, and if the individual tendencies were linear or if joinpoints existed. In addition, a global model was also created and its accuracy tested by predicting the number of bites for 2018 and comparing that prediction with the actual number for that year.

Between 2000 and 2016, more than 80% of all shark bites occurred along the US and Australian shorelines, whereas the US, including Hawaii, had nearly three times as many bites as Australia for this period (Table 1). When adding South Africa and New Zealand to the top two countries, these top four countries record more than 90% of the world's shark bites (Table 1).

The top four countries lacked joinpoints, as did the remaining six countries; thus, linear regressions models were considered. However, as already mentioned, using simple bite counts to determine trends would be incorrect. Hence, the bite counts were transformed into bite rates and then converted into the natural log. Regression models for three of the four top countries showed a negative "b" value, hence a negative slope (Table 1).

Creating a global model for the bite rates between 2000 and 2016 revealed a negative trend (Figure 1). Using this model to predict the number of incidents for 2018 revealed 88.3 incidents with a 95% interval ranging from 76.2 to 102.9 incidents. The number of verified cases for 2018 was 82.

4. Discussion

The global shark bite rates are decreasing. This trend is most likely caused by annually more people entering the

Table 1: Annual average shark bites and slope of the corresponding bite rate regression model for the top ten countries between 2000 and 2016. ⦰: average annual bite counts; SD: standard deviation; %: average annual percentage; b: slope of linear model $y_i = a + bx_i$ (see "Methods" for further explanation).

	⦰	SD	%	b
USA	47.5	9.7	60.4	-0.00125
Australia	15.9	5.4	20.2	0.02050
South Africa	5.9	2.7	7.5	-0.00274
Venezuela	2	2.3	2.5	-0.00824
New Zealand	2	1.4	2.5	-0.02043
Bahamas	1.7	1.1	2.2	0.31183
Réunion	1.4	1.9	1.8	0.15955
New Caledonia	1	1.3	1.3	0.05125
Egypt	0.7	1.3	0.9	0.00024
Mexico	0.6	1.2	0.7	0.00025

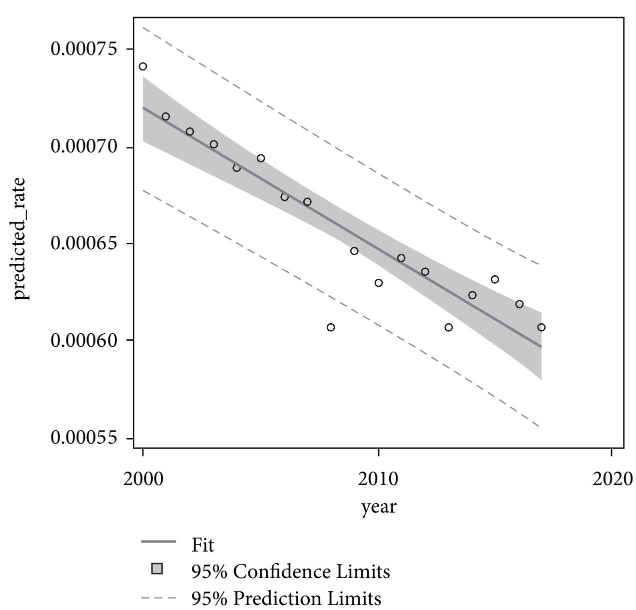

Figure 1: Global model for bite rates between 2000 and 2016.

water while the density of the incident-prone shark species decreases at the same time. Still, the number of people entering the water could be influenced by several factors, while the same is true for the sharks. In the following, several of these influencing factors are considered and discussed.

4.1. Factors Determining the Presented Trend Models. The very low number of shark bites each year makes it easily understood why there is a fluctuation of bites over time. This indicates that the annual bite rates likely depend more on national circumstances than global effects, besides the persistent overfishing of sharks. For example, a country may experience an increase in bites due to (a) more favorable meteorological circumstances throughout the year bringing more people to the beaches; (b) increased buying power allowing for more beach vacations; (c) the political stability of a country; or other factors. Of course, the reverse may also be true for another country throughout the same period; thus, the overall global bite rate trend is a result of all these influences for all the countries that report incidents with sharks.

Of more than 500 species of sharks, only about a dozen species are commonly involved in incidents. So even a commercial fishing loss of at least 70 million sharks each year [22–24] may not affect the annual bite rates should the incident-species not being targeted. However, most of them do indeed show up in fishery statistics [25, 26]. This situation then raises the question of why the annual bite counts still range in the same bracket throughout the examined period [17]. One possibility is that not all of these species are harvested with the same intensity since some of them live closer to shore, areas which are commonly excluded from commercial shark fisheries. Beyond the well-known tiger shark, *Galeocerdo cuvier*, and white shark, *Carcharodon carcharias*, it is the members of the genus *Carcharhinus* that predominantly cause incidents, such as bull sharks, *C. leucas*, blacktips, *C. limbatus*, spinners, *C. brevipinna*, or silky sharks, *C. falciformis*. Except for oceanic whitetips, *C. longimanus*, and silkies, many of those *Carcharhinus* species hardly ever venture into deeper waters, thus limiting their exposure to commercial fishing. Together with their shore-oriented distribution, their nursery grounds are also located along coastlines, and, should anthropological destruction remain low, they make shores their prime habitats. However, destruction of shorelines due to eutrophication [27, 28], dredging [29, 30], or even algal blooms [31, 32] is likely to reduce food fish for resident sharks, forcing those sharks to move into deeper water, away from potential areas where humans would be encountered. Deeper waters could also have a reverse effect, as observed, for example, for the island state of Réunion. There, the topographical features limit the involved sharks to being part of resident populations, so largely eliminating transient sharks along those shorelines, making the resident sharks more prominent year-round [33, 34]. This situation around Réunion indicates that the two main species—the tiger shark and the bull shark—are not just part of resident populations; they also seem to be more shore-oriented, again, due to the deeper waters surrounding Réunion likely providing less food for these sharks. Although shark bycatch around Réunion exists [35], neither the most often caught blue sharks, *Prionace glauca*, nor oceanic whitetips cause incidents around the island.

Réunion represents a prime area for studying incident rates in more detail, even more so when bite rates are factored against the length of this country's shoreline [36]. Therefore, even though 90% of all yearly bites occur in the US, Australia, South Africa, and New Zealand, thereby influencing the global trend the most, a ratio between bite rates and length of the shoreline may put Réunion in a completely different position against those other top countries.

Although the drop in global shark bite rates seems to be a simple issue between an increase of world population against the overfishing of sharks, all the factors mentioned above contribute to the outcome of the global bite rates. Thus, it is imperative to examine each of these influences in more detail to determine which one may have the most effect on the presented outcome.

4.2. Do Shark Incident Trends Matter? When it comes to incidents between humans and predatory animals, sharks rank lowest with an average of less than a hundred bites per year [1]. Considering that sharks are abundantly present around the millions of people entering the sea every day, these bite counts are extremely low [13–15]. Still, these relatively few incidents are trumpeted by the press far more than those by any other animal. Such prejudice against sharks greatly exaggerates their actual threat to humans [3, 37, 38]. It is paramount for the sake of sharks that the general public finally understands that these animals do not present any grave statistical danger [1]. As a result of this unjustified fear, sharks are denied the protection they so desperately need [39–41]. One can only hope that the global decrease in bite rates will put people's minds at ease and ameliorate this unfair prejudice against sharks [42–44]. Changing the public's perception of sharks is crucial for both them and for the wellbeing of our oceans. Sharks still represent the most abundant top predators over 50 kg in the marine realm; as such, they serve an essential function in the ecosystem [45–47]. It is no exaggeration to contend that any further reduction in their populations could trigger an irreversible imbalance of the oceans' food chains, leading to a catastrophic collapse of the entire marine realm itself [48, 49].

4.3. Prediction of the Bite Counts for 2018. The generally accepted assumption is that shark bites are increasing [10–12]. The foundation for the said assumption is based on the simple comparison of yearly bite counts. Such an approach is erroneous for two reasons: (1) not every incident between a shark and a human being counts, and (2) bitten persons are always part of a pool of people that offers the common denominator for different areas [13–16]. Ignoring these two focal points, predictions cannot be made. The application of including proxies of human populations in relation to actual bites, as well as eliminating incidents that have been provoked by, for example, shark fishing or shark feeding, transforms these bites into the more meaningful bite rates. These rates are decreasing on a global level. As mentioned above, the simplest scenario that could lead to such a decrease is the continuous global overfishing of sharks, combined with the increase in world population. Since neither of the two will stop, the posited prediction remains: bite rates will keep dropping in the future.

Our regression model predicted 88.3 incidents for 2018 with a 95% confidence interval ranging from 76.2 to 102.9 incidents. This confidence interval puts the actual number of 82 right within the predicted range. As long as the same proxies for the human population are used for all involved countries and what qualifies for a legitimate incident, our prediction model offers a robust outlook for the years to come.

Using proper media channels, combined with mitigation programs [9, 50] to reduce the already low numbers of shark bites, may be the beginning of finally reversing the erroneous misconception that sharks pose a high-risk danger to humans.

Data Availability

All datasets are ready to be sent, upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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