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Shark Bite Rates Along the US Gulf Coast: A First Investigation

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Abstract

The Gulf of Mexico is recognized as being home to all the shark species commonly involved in incidents with humans. SatScan^{TM}, a spatial and space-time statistical tool, was used to determine high-risk and low-risk clusters of bite rates caused by these species along the US Gulf of Mexico coast. The in-existence of any significant high-risk clusters along the coast suggests low shark densities in these waters. Overfishing is probably the most limiting factor but other anthropogenic influences, like altering or destroying shore areas which are commonly used for nursery grounds by these species, may also contribute to the overall low densities. However, each incident is also an independent event of a shark's decision-making to either proceed or abort an encounter before making human contact. Whenever discussing factors influencing shark bite rates, decision making by an individual shark should be part of it.

Keywords: Bite Rate, Decision-Making, Gulf of Mexico, Shark Density

Introduction

The risk of humans getting bitten by sharks is increased in certain areas along the continental US East coast (Amin et al., 2012, 2014). This is especially true for some regions in the Carolinas, as well as Florida, like Volusia County, a high-risk area on its East coast. However, counties along the West coast of Florida reflect the opposite (unpublished data). This fact is rather surprising considering that the West coast of Florida opens up to the Gulf of Mexico with its warm waters enabling beachgoers to pursue their water activities practically all year long. Considering the subtropical latitude of the Gulf of Mexico as well as being the home of over forty shark species, including the incident prone tiger sharks, *Galeocerdo cuvier*, bull sharks, *Carcharhinus leucas*, and even white sharks, *Carcharodon carcharias,* bite rates are surprisingly low. Although the latter species is fairly rare in the Gulf, with no incident occurring within the last 100 years (GSAF, 2018), bull and tiger sharks are quite common (e.g., Carlson and Brusher, 1999; Cruz-Martinez et al., 2004; Scott-Denton et al., 2011). Additionally, beside the bull shark, most of the other commonly in incident involved *Carcharhinus* species also give birth in the Gulf of Mexico. The majority of them do so in shallow areas such as estuaries, and river mouths, bringing them at least temporarily close(r) to populated beaches during their natural migration patterns to and from nursery grounds or in search of food, mating partners and others (e.g., Bres, 1993; Carlson, 1999, 2002). As a consequence, an increase in bite rates could be expected along populated beaches in these areas. However, that is not the case for the shores along the US Gulf coast.

An unpublished evaluation showed that the West coast of Florida, which is part of the Gulf coast, only shows low bite rates. This is likely caused by a combination of factors including overfishing of the incident prone species, nursery ground destruction as well as the chosen activities of beachgoers. Thus, it could be assumed that the same factors determine the bite rates along the rest of the Gulf coast, beyond Florida's borders.

Here, we examine the shark bite incidents along the entire US Gulf of Mexico shoreline between 1994 and 2009, with special emphasis on the coast between Alabama and Texas and compare them with the ones mentioned for Florida's West coast. Although the factors involved reflect the most likely scenarios, we will also briefly discuss another aspect that always influences the bite rates for any given area: a shark's decision-making of either aborting or proceeding with a potential contact when in the vicinity of a human being (Ritter and Amin, 2015). Although this aspect cannot be easily quantified or qualified at this time, it is relevant to understand that every bite ultimately depends on the individual decision a shark makes while in close(r) proximity to a person.

Materials and Methods

The time period between 2004 and 2009 was chosen to enable comparison with the results of our earlier work covering the same duration of time (Amin et al., 2012, 2013, 2014).

Forty-eight counties make up the Gulf coast between Florida and Texas. In this study, each of these counties is defined as one specific region.

The number and location of bites was obtained from the Shark Research Institute‘s 'Global Shark Attack File' (GSAF, 2018). Incidents involving an unnatural increase in the risk of getting bitten by a shark like any type of fishing, including spearfishing, were excluded from the analysis.

In order to define the relative number of incidents in the respective counties, we used 'bite rates,' a ratio defined in earlier work (Amin et al., 2012, 2013, 2014). Bite rate reflects the ratio between the annual reported shark bites for a region and the estimated beach attendance for the same region and time. For this study, however, beach attendance data were incomplete and substituted with the coastal population for the respective region, gathered from the United States County Intercensal Tables.

Statistical modelling

In the past, we used SatScan^{TM}, a spatial and space-time statistical tool (Kulldorff, 1997, 2015), to evaluate a region’s bite rate in comparison to other regions. This software program scans over geographical areas by using the coordinates of latitude and longitude for the individual regions, called centroids. It then creates a window that moves spatially over the entire predetermined area, in this case the US Gulf coast. This window includes a variety of sets of adjacent regions represented by their corresponding centroids. If the centroid of a region is included in the moving window, that region is added and so the radius of the window for each grid point varies continuously in size, starting at zero up to a specific upper limit. To detect clusters, the spatial scan statistic is tested first. In a second step, the space-time scan statistic is then utilized by creating a cylindrical window testing the circular area for geographic data where the height of the cylinder represents time. Kulldorf (1997, 2015) gives a detailed description about how these windows connect and how the circular clusters are identified.

A discrete Poisson model was implemented in this study, since shark bites are independent and sporadic, thus the variables could be assumed to follow the Poisson distribution

$$P\{x \mid \mu\} = \frac{e^{-\mu}\mu^{x}}{x!}$$

where μ and x are the average and actual number of bites, respectively, x! reflects the factorial of the bite numbers, and P{x|μ} is the probability that there are x incidents for a given time period.

SaTScan^{TM} then tests the null hypothesis that there is an equal chance of being bitten by a shark in every region versus the two alternative hypotheses that there is a higher risk in a particular region, as well as a lower risk in a particular region. The likelihood function used in SaTScan^{TM} is

$$\left(\frac{n}{E}\right)^{n}\left(\frac{N-n}{N-E}\right)^{N-n} I(n > E)$$

where n and E are the observed and expected number of shark bites within the window, and N stands for the total number of incidents in the study area. N-E reflects the expected number of shark bites outside the window, with I as the indicator function. To attain the p-value for the likelihood ratio, SaTScan™ uses Monte Carlo testing by producing 999 random simulations. For a cluster to be statistically significant, the p-value needed to be less than 0.05. Depending on the likelihood ratio, clusters were then labelled as primary, secondary etc. in descending order.

Species identification

The likely species involved was mentioned in only eleven cases. However, in none of these incidents was the species truly verified, hence we refrain from any speculation about species involvement for any of the cases mentioned in this study and use the general list of commonly involved species (GSAF, 2018).

Results

Between 1994 and 2009, 43 shark bites were confirmed for the 48 counties along the Gulf coast between Monroe County, Florida, in the East and Cameron, Texas, in the West.

High-risk cluster areas

There was no region along the Gulf coast examined that represented a significant high-risk cluster of bite rates. The county with most elevated risk was Galveston County, Texas, with a p-value of 0.186 and a relative risk of 4.51 (Table 1). This indicates that the probability of an incident in Galveston county to the probability of an incident in the rest of the Gulf coast is 4.51 times higher. However, the non-significant p-value indicates that the null hypothesis cannot be rejected; thus, there is an equal chance of getting bitten by a shark elsewhere along the Gulf coast. The same is true for the shoreline between Franklin County and Gulf County, Florida, with a relative risk of 14.55, but likewise a non-significant p-value.

Low-risk cluster areas

The shoreline between Mobile County, Alabama, and Chambers County, Texas, reflected the most significant low-risk cluster with a p-value of 0.000016 (Table 1). No other significant low-risk cluster area could be identified along the Gulf coast although the shoreline between Dixie County and Pasco County in Florida showed a tendency for having lower than expected incidents as well ($p = 0.159$).

Space-time cluster areas

Five time-related spatial clusters were identified along the Gulf coast, but none with a p-value of less than 0.05 (Table 2). The most prominent area was Galveston County, Texas, between 2004 to 2005, with a relative risk of 22.46.

Human activities

Activities like spearfishing were not included in this study since they unnaturally increase the risk of getting bitten by a shark, thus the remaining activities were wading/playing, swimming and surfing, with percentages of 33.3, 28.6 and 38.1, respectively.

Discussion

Efforts to understand why sharks occasionally bite humans have a long history, thus it is surprising that for the majority of incidents in the study area, the actual species involved were not identified (GSAF, 2018). While it is generally agreed which species are most often involved, even a tentative identification still remains mostly speculative as no taxonomic features are commonly discerned, and no actual wound analysis was performed which would allow the involved species to be identified (Ritter and Levine, 2004, 2005; Levine et al., 2014). For Florida waters, and by extension for the Gulf of Mexico, most incidents are likely caused by species of the genus *Carcharhinus* like blacktip sharks, *C. limbatus*, spinners, *C. brevipinna*, silkies, *C. falciformis*, and the already mentioned bull sharks. The dusky shark, *C. obscurus*, closely resembling the bull shark, is possibly responsible for some of the incidents falsely attested to the bull shark. But it is not only bull sharks that have sometimes incidents erroneously attributed to; the same is true where blacktips, silkies and spinners are concerned. Not only is their overall appearance very similar, the wounds are also almost identical due to the similarity of teeth and jaw sizes. Even so larger silky sharks show serration in their upper teeth which is lacking in the other two species. Serrated teeth can lead to less frazzled wound margins should the shark shake its head back and forth. But since bites reflect mostly puncture wounds without any drawing, the difference in upper tooth shape barely manifests itself.

Shark bite incidents most often happen very quickly, and a visual recognition of the involved shark is hardly possible, even less so should the animal be smaller where typical features are often more difficult to recognize and differentiate. Although species identification may not matter in the outcome of an incident, as long as infection is of no concern (e.g., Unger et al., 2014; Isci and Ritter, 2018), it is still crucial in understanding what drew a particular shark close(r) to shore.

Previously, we compared bite rates between the East and the West coast of Florida (unpublished data). This showed that the East coast not only has a significantly higher occurrence of bites, but in comparison to other incident prone areas around the world, it also represents the world's most exposed coastline (Amin et al., 2012). We concluded that the most plausible reason for lower bite rates along the West coast of Florida was a combination of generally lower population densities of the incident prone species due to overfishing, reduced nursery grounds connected to additional anthropogenic influences that further degrade shore habitats, as well as fewer surfers, as this is the activity most associated with shark-related incidents (e.g., Amin et al., 2012, 2013). Overall, the lower density of the various shark species commonly involved in biting incidents seems to be the most determining factor in the differences observed. However, as we will discuss later, the issue of decision-making by an individual shark to further approach and possibly bite, or abort and swim away remains a most crucial factor.

Areas of potential encounters between sharks and humans

Large stretches along the Gulf coast of Florida are inaccessible for beachgoers, effectively reducing potential contact zones. The very large low cluster region between Mobile County, Alabama, and Chambers County, Texas, consists also mainly of inaccessible beaches, with a few exceptions. Although these isolated shorelines may only reflect a lack of access to otherwise suitable beaches, most of the time these areas are truly unsuitable for beach activities, for example such as marshes, estuaries, river deltas and other zones. These habitats are typically frequented by resident shark species and used as nursery grounds (e.g., Carlson and Brusher, 1999; Carlson, 2002; Bethea et al., 2004), as well as protected habitats for younger sharks, or smaller species (Heupel and Hueter, 2002; Heupel et al., 2007). With the exception of silky sharks and duskies, all of the above mentioned *Carcharhinus* species give birth in these shore waters where their offspring then either reside for longer periods of time until they are large enough to wander off into deeper or more open waters (e.g., Bethea et al., 2006; Knip et al., 2010), and then be exposed to predation by larger sharks, or they travel along shorelines, remaining in relatively shallow areas.

The rather small areas suited for public beaches along the Gulf coast are well frequented by all kinds of water sports enthusiasts. It would be there where encounters with sharks would be most likely to occur, but the overall low bite rates contradict this assumption. This could mean that members of the incident prone species do not frequent these shorelines much, or their overall density is indeed low. The latter is the most likely possibility, considering coastal-resident species like the blacktip and sandbar sharks have been heavily fished (e.g., Carlson, 2002). Blacktip sharks were commercially the most harvested species in the Gulf in the recent past (e.g., Keeney et al., 2003), but their low fecundity rate of approximately 4-6 pups every other year (e.g., Castro, 1996) and slow growth made them declared overfished by 1998 in the Gulf of Mexico, as well as the Western Atlantic.

Blacktip sharks, and all the other shark species harvested around the globe are considered K-selected species, which reflects a low fecundity, late maturity and slow growth. Thus, only a total ban on fishing for selected shark species, or at least very drastic restrictions, could bring populations back (e.g., Baum and Myers, 2004).

Human activities

When looking at the types of water activities, none of them stands out along the Gulf coast, including surfing which reflects close to 60% of the activities on the East coast of Florida when a bite occurred (Amin et al., 2012). Although one could argue that plausibly more surfers frequent the East coast than the Gulf region, where surfing was only part in 38% of all incidents, comparing percentages is not a valid option to make a conclusion since the actual number of people involved in the different activities over a certain time period is unknown. However, although surfing in the Gulf area entails only 38% of all incidents, this activity could still be more attractive than the percentage suggests, should the actual numbers of surfers be smaller in direct comparison to those who make-up the remaining 62%. Similarly, low bite numbers along populated beaches do not allow the conclusion beyond any reasonable doubt, that less sharks visit those areas, as indicated above. It could very well be that there are plenty of sharks which regularly frequent such beaches but collectively withdraw because of the loud noises humans create when in the water, and so preferably only dare to get closer when a person is more isolated.

In the end, only the true number of people being in the water at a given time involved in a specific activity can reveal exact results. Nevertheless, the most likely scenario for the Gulf coast can still be garnered from the combination of percentages, ratios and rates, even more so since the situation along Florida's West coast reflects the same potential factors explaining low bite rates (unpublished data).

Ignoring a shark's decision-making?

Lower shark population densities, destruction of nursery grounds, and any other anthropogenic factors affecting a shark's biology and survival contribute directly or indirectly to lower bite rates. Although this array of factors likely influences bite rates the most, decision-making by a shark to go for, or abort an approach ultimately determines whether an incident happens or not.

Scientific literature offers a number of ideas why sharks bite on rare occasions (e.g., Ritter and Levine, 2004, 2005; Ritter and Quester, 2016), but has largely ignored why a shark would abort an encounter when in close vicinity to a human being. The way a shark approaches a person depends on a variety of factors and moving closer does not happen by chance (Ritter and Amin, 2012, 2014, 2015). Since approaching from behind is a primary way of closing the distance (Ritter and Amin, 2014, 2015), chances are that people frolicking in the water, swim or surf, likely do not see a shark approaching and then abort, otherwise the media would be full of sightings year round. Since the yearly worldwide bite numbers hardly reach 100 cases, sometimes considerably less (GSAF, 2018), despite the millions of people entering the water on a daily basis, it must be true that the great majority of sharks terminate an encounter before contact is made.

Overfishing of sharks (e.g., Baum and Myers, 2004; Shepherd and Myers, 2005; Davidson et al., 2016), combined with their wrongful image as being dangerous animals (e.g., Ritter et al., 2008; Ritter and Amin, 2017), brought many shark species to the brink of extinction. It does not matter that the number of incidents between sharks and humans is by far the lowest compared to any other large predator commonly involved with humans (e.g., Ritter and Amin, 2017).

The simple fact that incidents happen, even on such a low scale, is reason enough to mark sharks as being vicious animals. Their negative image hampers their protection which will eventually lead to their demise, triggering a plethora of unpredictable ecological chain reactions within the marine realm. The wrongful image of sharks is closely connected to incidents. If as much effort as is put in to highlight those rare incidents in the media, made to spread the fact that for every incident a multitude of encounters are aborted before contact is made then our perception of these creatures may change.

Conclusion

Bite rate clusters along the US Gulf coast depend on a variety of factors. However, the overall very low bite rates suggest a rather prominent and encompassing effect such as overfishing of the incident prone species. But no matter the external circumstances influencing the bite rate, the outcome of every encounter comes down to the shark's decision to either proceed or abort an encounter. Although the reasons for a shark's decision can only be guessed, its effect is reflected in the overall bite numbers. To that extent, although it is likely that the biggest factors in overall bite rates are a lower density of shark populations, reduced nursery grounds and other general anthropogenic factors, an individual shark's decision to go for or abort an encounter must always be included when contemplating determining factors.

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Table 1. Spatial data for the high- and low-risk cluster areas along the US Gulf coast between 1994 and 2009. Area = counties; R_{rel} = relative rate; N_{true} = actual bite numbers, RR = relative risk; N_{exp} = expected number of bites; *p* = p-value of log-likelihood ratio test.

Area	R_{rel}	N_{true}	**RR**	N_{exp}	***p***
Galveston, TX	primary high	6	4.51	1.49	0.186
Franklin, FL – Gulf, FL	secondary high	2	14.55	0.14	0.297
Mobile, AL -Chambers, TX	primary low	0	0	11.20	0.000016

Table 2: Space-time data for the high- and low-risk cluster areas along the US Gulf coast between 1994 and 2009. Area = counties; Time = duration when cluster appeared; R_{rel} = relative rate; N_{true} = actual bite numbers, RR = Relative risk; N_{exp} = expected number of bites; *p* = p-value of log-likelihood ratio test.

Area	Time	R_{rel}	N_{true}	RR	N_{exp}	*p*
Galveston, TX	2004-2005	primary high	4	22.46	0.2	0.077
Santa Rosa, FL - Baldwin, AL	1999-2001	secondary high	5	9.33	0.6	0.384
Franklin, FL – Gulf, FL	2002-2005	secondary high	2	57.37	0.037	0.455
Monroe, FL -Lee, FL	2004-2009	secondary high	8	4.50	2.08	0.667
Manatee, FL - Plaquemines, LA	1994-1998	primary low	0	0	6.29	0.115

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