

Individual shark profiling: An innovative and environmentally responsible approach for selectively managing human fatalities

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Abstract

Most shark-induced human fatalities are followed by widespread and unselective culling campaigns that have limited effectiveness and may have high ecological costs for threatened species. The blanket culling strategy implicitly assumes that incident risk is directly correlated with shark density, an assumption that has yet to be demonstrated. We present the alternative hypothesis that incidents are more likely to be caused by behavioral variability among individual sharks than due to shark density. Throughout their ontogenetic development, large species of sharks opportunistically establish a diet that is rarely, if ever, inclusive of humans as a food source. We propose that, some animals with specific behaviors (including boldness) may potentially pose a higher risk than conspecifics. Under this scenario, the risk of a shark attack in a given area would relate to the presence of a limited number of high-risk individuals rather than shark density.

In terms of management of human fatalities, such a hypothesis would favor abandoning general culling campaigns and replacing them with approaches that profile and selectively remove the potential problem individuals, as is done in the terrestrial realm when managing predators that attack humans or livestock.

KEYWORDS

agonistic behavior, blanket culling campaigns, carnivore risk management, fatal attack, human-wildlife conflict, problem individuals

1 | INTRODUCTION

Widespread lethal control of predators has historically been the most common strategy used in response to wildlife attacks on humans (Rasker & Hackman, 1996). In the terrestrial realm (Table 1), these unselective policies have been increasingly replaced by more selective approaches that focus on individual “man-eaters” or “problem individuals” (Swan, Redpath, Bearhop, & McDonald, 2017), however, little has changed in the marine realm. For sharks, behaviors toward humans that end in fatalities still lead to culling

campaigns such as those conducted over the past 5 years in Western Australia (Gallagher, 2016) and on the French island of La Reunion (Cressey, 2013). These campaigns have detrimental effects on the conservation status of already threatened species and their effectiveness is questionable (Ferretti, Jorgensen, Chapple, De Leo, & Micheli, 2015). Besides the negative ecological impact, these campaigns also failed to alleviate the impact of the shark “attack” crisis on local economies that rely on tourism (Lagabrielle et al., 2018). Part of the reason that such ineffective campaigns continue may be that managers have lacked the evidence demonstrating why culling campaigns are largely ineffective.

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TABLE 1 A set of questions that can help understand the mechanisms of shark attacks and help develop appropriate management responses

Hypothesis	Type	Question	Reaction
Density-dependent mechanisms	None	Are shark bites widespread, regular, and related to shark density?	If yes, then general lethal control of sharks to lower shark density may be appropriate to the extent that it is viewed as acceptable, or there is a need to implement widespread mitigation.
Behavioral mechanisms	Type 1 Problem individual – an individual in the wrong place	Question 1: Does the attacking species of shark normally reside in the area of the bite or is it only an occasional and unpredictable occurrence?	If it is only an occasional vagrant, then no reaction is needed or indeed possible apart from being ready to react to events with beach closures
		Question 2: Are bite locations associated with specific landscape features (prey aggregations, movement corridors, or underwater topography that serves some other function for sharks) that lead to locally high densities of sharks?	If attacks are spatially clumped, then it is possible to discourage risky human activities in such areas or implement mitigation measures such as netting on these sites.
	Type 2 Problem individual – individuals with a specific “undesirable” behavior	Question 3: Do individual sharks or sharks of specific age and sex, demonstrate consistent feeding specializations?	If the answer to these questions is yes, then it opens the way for a selective removal of individuals.
		Question 4: Do individual sharks or sharks of specific age and sex, demonstrate consistent responses to humans (or human decoys)?	
		Question 5: Are shark bites spatially and temporally aggregated into clusters?	
		Question 6: Is it possible to forensically identify problem individual and then recognize them in the field?	
		Question 7: If a shark is identified as a perpetrator can it be located and selectively removed?	

Note: This is largely based on the conceptualization of problem animals developed from terrestrial carnivores (Linnell & Alleau, 2015; Linnell et al., 1999).

Based on experience from terrestrial systems, we propose a new approach for improving sea-users' safety that addresses the likely pattern of shark incidents and explains the failure of culling campaigns to reduce the risk in a satisfactory way, both in terms of human safety and ecological impact. We propose that new studies (Table 2) should be undertaken to identify individual sharks in order to eventually selectively cull “problem” animals. This approach has the potential to reduce the negative ecological effects currently posed by nonselective shark culling campaigns, to alleviate the conflicts with communities opposed to them, and might also help to globally improve the relationship between humans and sharks worldwide.

2 | THE BEHAVIORAL HYPOTHESIS

Shark-culling campaigns as a response to human fatalities after a shark incident are conducted to reduce the probability of shark-human interactions (Dudley, 1997), based on the implicit assumption that human fatalities are driven by greater-than-acceptable shark abundance (Ferretti et al., 2015), which we refer to as the “density-dependent hypothesis.” In other words, reducing the risk of human fatalities by reducing the shark population *de facto* relies on the assumption that every shark represents an equal risk level to humans. It also assumes that lowering the density of sharks will lower the probability of a human being killed (Figure 1).

TABLE 2 Research themes to be developed following the behavioral hypothesis aiming at the selective removal of problem individuals in the context of human fatalities

Questions	Approaches to be tested
1. Better knowledge of dangerous species	1.1 Acoustic tagging ^c for identifying the presence of potential problem individuals in a given area (i.e., a beach) 1.2 Satellite tagging ^d for studying the ecological behavior of potential problem individuals
2. Identification of problem individuals	2.1 Underwater photoidentification ^e and photogrammetry ^f (for size assessment) of individuals combined with ethological tests ^g for assessment of risky behaviors (i.e., individual variation and consistency in boldness or aggression) toward humans 2.2 Live capture and blood sampling for assessment of hormones as indicators of boldness ^{h,i} 2.3 Forensic analysis of human bites/fatalities for identifying the species and individual ^{j,k} (size assessment through interdental distance) 2.4 Collection of shark DNA fragments on human wounds (after a bite) to identify the species (barcoding on mitochondrial DNA ^l) and the individual (fingerprinting on microsatellites ^m)
3. Removal of problem individuals^a	3.1 Species and size assessment through underwater photogrammetry ^f for assessing the size of potential attackers (which could match with existing data; see 2.3) 3.2 DNA sampling (biopsies) for individual fingerprinting ^m (on microsatellites) and development of a database of potential attackers. This would allow a potential match with data obtained from human victims (see 2.4)

Note: For questions 2 and 3, it is suggested to use odor attractants or artificial food provisioning^b in order to temporarily aggregate large sharks as they are very elusive animals. Such aggregations would allow facilitated studies of behaviors, DNA and blood sampling, tagging, or even fishing (removal) of specific individuals.

^aThis could be done underwater following the matching of DNA fingerprinting obtained from a human victim (see 2.4) and from the parallel DNA sampling of animals (see 3.2). The problem individual to be removed would then be reidentified on the aggregation site through photoidentification and accurate size assessment through photogrammetry (see 2.1).

^bBrena, P.F., Mourier, J., Planes, S. & Clua, E. (2015) Shark and ray provisioning: functional insights into behavioral, ecological and physiological responses across multiple scales. *Marine Ecology Progress Series*, **538**, 273–283.

^cMeyer, C.G., Clark, T., Papastamatiou, Y.P., Whitney, N.M., & Holland, K.N. (2009) Long-term movement patterns of tiger sharks *Galeocerdo cuvier* in Hawaii. *Marine Ecology Progress Series*, **381**, 223–235.

^dHammerschlag, N., Gallagher A.J. & Lazarre, D.M. (2011) A review of shark satellite tagging studies. *Journal of Experimental Marine Biology Ecology*, **398**, 1–8.

^eDomeier, M.L., & Nasby-Lucas, N. (2007) Annual re-sightings of photographically identified white sharks (*Carcharodon carcharias*) at an eastern Pacific aggregation site (Guadalupe Island, Mexico). *Marine Biology*, **150**(5), 977–984.

^fRohner, C.A., Richardson, A.J., Marshall, A.D., Weeks, S.J., & Pierce, S.J. (2011) How large is the world's largest fish? Measuring whale sharks *Rhincodon typus* with laser photogrammetry. *Journal of Fish Biology*, **78**(1), 378–385.

^gBrena, P.F., Mourier, J., Planes, S., & Clua, E.E. (2018) Concede or clash? Solitary sharks competing for food assess rivals to decide. *Proceedings of the Royal Society B*, **285**(1875), 20180006.

^hArchard, G. A., Earley, R. L., Hanninen, A. F., & Braithwaite, V. A. (2012). Correlated behavior and stress physiology in fish exposed to different levels of predation pressure. *Functional Ecology*, **26**(3), 637–645.

ⁱRaoult, V., Brown, C., Zuberi, A., & Williamson, J. E. (2012). Blood cortisol concentrations predict boldness in juvenile mulloay (*Argyrosomus japonicus*). *Journal of Ethology*, **30**(2), 225–232.

^jLowry, D., de Castro, A.L.F., Mara, K., Whitenack, L.B., *et al.* (2009) Determining shark size from forensic analysis of bite damage. *Marine Biology*, **156**, 2483e92.

^kClua, E., & Reid, D. (2018) Contribution of forensic analysis to shark profiling following fatal attacks on humans. *Post-mortem examination and autopsy-current issues – From death to laboratory analysis*. (Ed. K.H. Dogan), chapter 5, pp. 57–75. Intech Open Science.

^lFields, A. T., Abercrombie, D.L., Eng, R., Feldheim, K., & Chapman, D.D. (2015) A novel mini-DNA barcoding assay to identify processed fins from internationally protected shark species. *PloS one*, **10**(2), e0114844.

^mChambers, G.K., Curtis, C., Millar, C.D., Huynen, L., & Lambert, D.M. (2014) DNA fingerprinting in zoology: past, present, future. *Investigative genetics*, **5**(1), 3.

Although there was a decrease in human fatalities in protected beaches after the implementation in 1937 of the Shark Meshing Programme in New South Wales (Australia), Green, Ganassin, and Reid (2009) showed that the annual rate of agonistic interactions with humans was the same both before and after the meshing program commenced, that is, 61 (1900–1936), 61 (1937–1973), and 72 (1974–2009), respectively. This is mainly due to a significantly greater number of sea-users as a determining factor for explaining a

constant or slightly increasing number of shark incidents for recent decades (West, 2011). The same trend was detected in the United States where the individual risk for ocean users dropped by >91% over a 63-year period (1950 to 2013; Ferretti *et al.*, 2015). The lack of specificity is another limiting factor of the general culling campaigns, as raised by Paterson (1990) who pointed out that while the white shark *Carcharodon carcharias* was responsible for 68% of fatalities in Australia, this species represented only 1.7% of catches among

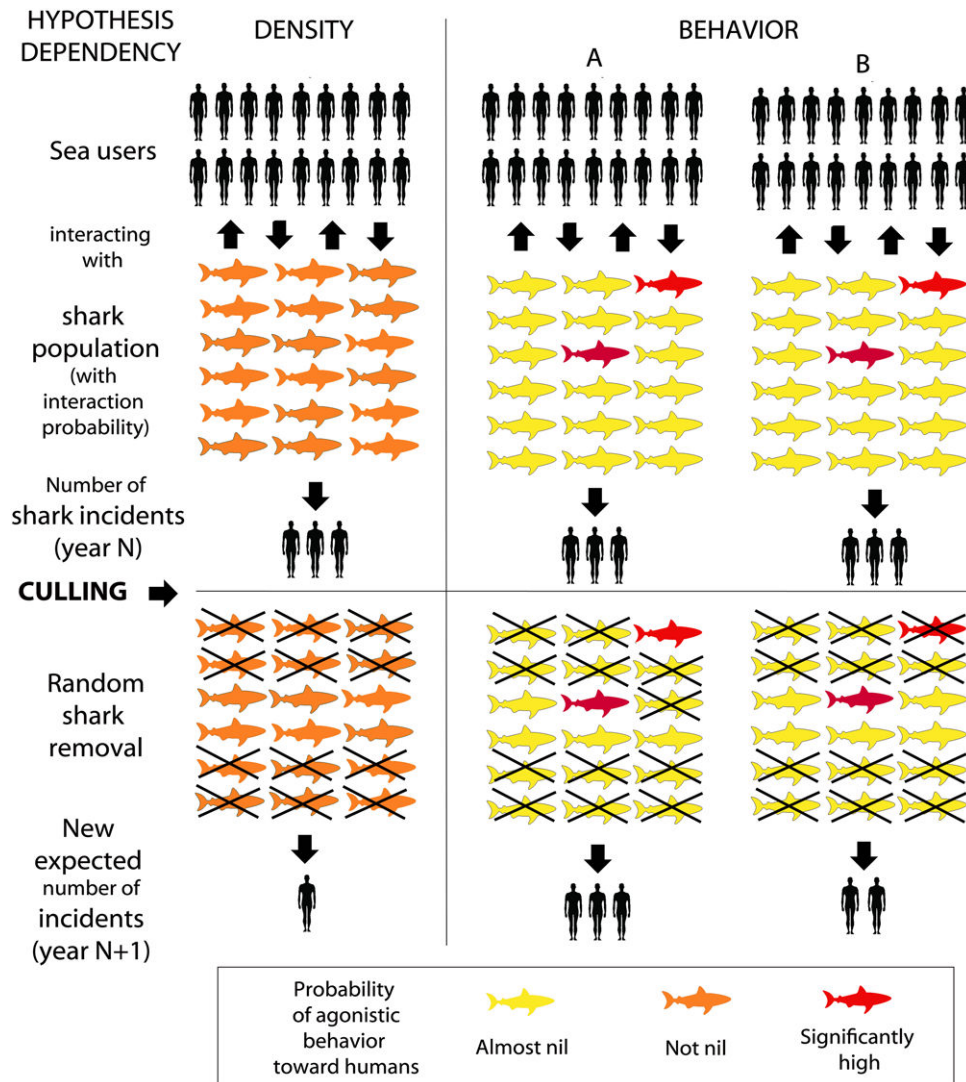


FIGURE 1 Schematic representation of the patterns of shark fatalities and the consequences of shark culling campaigns while accounting for either the « density-dependent hypothesis » (left) or the « behavior-dependent hypothesis » (right). For our demonstration, and for a given and similar population of sea users interacting with a shark population, the expected number of victims can arbitrarily be set at three victims per year. Following the « density-dependent hypothesis », each individual in the shark population is likely to kill humans with a non-zero probability (orange animals). After removing a large proportion of the shark population (here 66%), the number of fatalities would be significantly reduced (also by 66%) and would drop from three to one victim per year; whatever the number of sharks removed, this trend should persist. Following the « behavioral hypothesis » (right), the probability of a human fatality relates to a limited number of high-risk individuals (here two animals in red), while this probability is almost nil for the rest of the population (yellow animals). A: By removing the same fraction of the shark population as in the first case but failing to remove the high-risk individuals (option A), no change in the number of shark fatalities would be observed, and the annual rate would again be three victims. B: However, by catching one of the high-risk animals (option B), the annual rate would drop to two victims.

the 30,630 sharks that were culled with the Queensland meshing and baited lines program between 1962 and 1988.

Regarding their global efficiency, the first comprehensive study conducted on a shark control program looked at a case study from Hawaii between 1959 and 1976, where 4,668 sharks (including 554 tiger sharks *Galeocerdo cuvier* as the species responsible for feeding strikes on surfers) were killed and “no measurable effects on the rate of shark fatalities in Hawaiian waters” were recorded (Wetherbee, Lowe, & Crow, 1994). In this study, an average rate of 0.6 fatal

“attacks” per year was recorded before and persisted during the culling, with an increase to 1.4 per year during the years following the program. In Eastern Australia, over the past 70 years, around 500 targeted White sharks were caught (Reid, Robbins, & Peddemors, 2011), when recent research suggests there is a current population of 2,500 to 6,500 individuals on the East coast (Hillary et al., 2018). During 70 years, extensive and expensive culling programs (>\$A2m/year; Green et al., 2009) have, at best, caught 20% of the current white shark population, which would be unlikely to reduce

shark bite levels significantly. Thus, broad-scale culling, based on the density-dependent hypothesis, seems extremely inefficient.

We propose that human fatalities relate more to behavioral variability among individuals rather than shark population density, and attack risk is therefore generally independent of shark density in a given area. In our opinion, some individuals can show a suite of specific behaviors (e.g., size, habitat use, inclination for exploration, boldness) that make them higher-risk animals that do, on rare occasions, meet the condition for a feeding strike on a human. We hypothesize that the few individuals to do so would be the predominant source of lethal bites on humans, while other conspecifics would have a very low probability of killing humans. As a consequence, a kind of “everything or nothing” rule applies when shark culling is operational in a given area, meaning that solving the problem of shark fatalities will strictly rely on the chance capture of the problem individuals among the many that are killed. Provided that such campaigns fail to remove the single or the very few individuals with a high risk of predatory behavior toward humans (given their scarcity and the high mobility of certain species), the risk of human fatalities would not be reduced as expected (Figure 1A, B).

To support our hypothesis, we hereby: (1) demonstrate the potential for individuality to drive the feeding habits of large sharks and (2) illustrate how this hypothesis, if accepted, opens opportunities for new and practical management approaches.

2.1 | Diet and large sharks: An individual issue

Animal behavior was recently identified as a key modulating factor in the study of food webs (Kalinkat, 2014). Individual niche width depends on the diversity and abundance of available resources as well as on individual phenotypic traits (Araújo, Bolnick, & Layman, 2011) and individual behavioral skills and preferences (Kim, Tinker, Estes, & Koch, 2012). Personality in animals describes consistent behavioral differences across time and contexts between individuals within the same population (Stamps & Groothuis, 2010). Previous work has shown that individualities in fish are prevalent, including consistency over time and context (Castanheira, Herrera, Costas, Conceição, & Martins, 2013). The potential for this has long been established among mammalian predators (Graham, Harris, Matejusová, & Middlemas, 2011; Linnell, Odden, Smith, Aanes, & Swenson, 1999), and individual personality differences among sharks were recently described, in particular along the shy-bold continuum (Brown, Jones, & Braithwaite, 2005; Byrnes & Brown, 2016) and propensity for exploration (Finger, Dhellemmes, & Guttridge, 2017).

It is important to note that unlike mammals that are capable of transgenerational information transfer, large sharks must

individually develop their own predator skills due to the lack of any postpartum parental care. For instance, while juvenile Killer whales *Orcinus orca* can learn which prey to target and how to hunt from older pod members (Guinet & Bouvier, 1995), juvenile white sharks develop their own feeding strategy independently from conspecifics during the ontogenetic dietary shift that is characteristic of the species (Estrada, Rice, Natanson, & Skomal, 2006). When white sharks reach the size threshold of ~3 m in total length (TL), their diet shifts from small teleosts to larger prey such as other elasmobranchs and marine mammals (Kerr, Andrews, Cailliet, Brown, & Coale, 2006). In the unlikely event that a white shark encounters a human during the establishment of its new diet, it might test it as a potential prey item of suitable size and may include it as a future diet component. While diet transition periods constitute an opportunity for juvenile sharks to test new potential prey items (Clua & Reid, 2013), older animals may also constantly try to expand their diet niche based on their current needs (e.g., during shortages of their habitual feeding resource, or as a function of their current hunting abilities or food deprivation status) and according to their individual personality trait along the boldness continuum (Byrnes & Brown, 2016) or their exploration inclination (Finger et al., 2017). As described for a set of different taxa (Wilson, Clark, Coleman, & Dearnsteyne, 1994), large sharks would then individually range along the shy-bold and exploration continua, and their position might be modulated by food deprivation as a driving factor for a strike on humans (Godin & Smith, 1988). The “bite-and-spit” behavior that was described as a putative exploratory process for the white shark (Klimley, 1994), would fit perfectly with our hypothesis as a preliminary step toward including a new prey item in their diet. As a matter of fact, for many human fatalities, victims lose hardly any flesh or tissue, and ultimately die from exsanguination (Clua & Séret, 2010). We therefore hypothesize that bites on humans are carried out by a very limited number of sharks which are bold enough (and hungry enough) to execute a first strike on humans, and in most situations, do so without consuming human flesh. These problem individuals would then either abandon this marginal prey item or include it in their diet, which would result in further strikes on humans. However, this does not require any specific affinity or prey specialization toward humans, as observed for “bold” bears that might increasingly feed on anthropogenic food sources until becoming “food conditioned” (Bentzen, Shideler, & O'Hara, 2014). In that respect, our hypothesis partially aligns with the “rogue” shark hypothesis which is often portrayed in the media in that both attribute attacks to a few individuals with specific feeding behaviors (Neff & Hueter, 2013). However, our hypothesis does not require the anthropomorphic and otherwise unlikely attributes of aggression and an active preference for humans as prey.

Several findings support our hypothesis as substantial ontogenetic and individual dietary variations have been described within a White shark population in the Northeast Pacific (Kim et al., 2012). Like for the White shark, it has been demonstrated that tiger sharks also show a dietary shift in prey selection (toward prey with a similar size to humans) that begin to occur at approximately 230 cm TL (Lowe, Wetherbee, Crow, & Tester, 1996). Similarly, bullsharks *Carcharhinus leucas* above 180 cm TL shift from small fishes to larger prey including mammals (Cliff & Dudley, 1991). We do not think it is a coincidence that these three species are responsible for more than 80% of fatal shark incidents with humans over the past five decades.

2.2 | A new approach focusing on problem individuals

The case studies from Hawaii and Eastern Australia both provide circumstantial evidence against the density-dependent hypothesis and open for an explanation supporting the behavioral hypothesis if human fatalities were carried out by very few mobile animals that were never captured through the culling effort (Figure 1A, B). Other circumstantial evidence can be inferred from events such as in Natal (South Africa) where four attacks, two of which were fatal, occurred during what became known as the “Black December” of 1957 (Wallet, 1983) or in New Jersey (United States) where the summer of 1916 was brutally marked by a series of fatal bites on swimmers (Fericola, 2001), although the responsibility of a single “problem individual” was never clearly demonstrated.

Neither of these case studies and events alone can prove or disprove either of the competing hypotheses behind shark fatalities. However, they do illustrate that the behavioral hypothesis is an equally, or even more, plausible explanation of the events, and that it therefore deserves due consideration. Our main critique of the literature is that it has generally failed to advance hypotheses of the potential mechanisms that lie behind human fatalities and has therefore failed to develop tests of the alternatives. This is where research and management practices have come further in the terrestrial realm, as they have: (1) developed good conceptual frameworks for potential mechanisms (Table 1; Linnell et al., 1999), (2) conducted research projects to understand individual behavior and run analyses that are designed to separate between competing mechanisms (Odden, Nilsen, & Linnell, 2013), and (3) used these insights to develop appropriate management actions that underline proactive conflict prevention, rather than nonselective reaction (Breitenmoser et al., 2005). We used this terrestrial experience to develop a set of conceptual and shark-specific questions (Tables 1 and 2) that are amenable to research and which could shed light on the nature of shark fatalities.

3 | CONCLUDING REMARKS

Although our brief review does not resolve the issue of the mechanisms behind shark incidents that remain poorly understood (Chapman & McPhee, 2016), it does open for an alternative interpretation that would logically call for dramatically different responses than those in common usage today. At the very least, we hope to stimulate field studies and management experiments that could shed more light on the mechanisms behind shark incidents and help develop more efficient (in terms of human safety) and less ecologically damaging responses. Furthermore, focusing management on individual animals could help to improve the reputation of sharks worldwide, as it would take the blame away from sharks in general and place the focus on a limited number of individuals (Swan et al., 2017).

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