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**'Selective removal of problem individuals as an environmentally responsible approach  
for managing shark bites on humans**

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1 Recent developments in ocean and coastal management

2

3 **Selective removal of problem individuals as an environmentally responsible approach**

4 **for managing shark bites on humans**

5

6 **Running title:** Management of shark problem individuals

7

8 **Abstract**

9 Selective removal of problem individuals following shark bite incidents would be consistent with  
10 current management practices for terrestrial predators, and would be more effective and more  
11 environmentally responsible than current mass-culling programs. In parallel, and in addition to  
12 traditional forensics analysis, we recommend the routine collection of shark DNA from wounds or  
13 devices following shark bite incidents in order to genetically identify the individual responsible.  
14 This approach would require creating an extensive database of shark identities in high-risk areas  
15 against which to compare DNA forensically recovered from shark bite incidents. At a local and  
16 regional scale, we propose utilizing existing shark tagging programs and artificial shark  
17 aggregation sites to collect DNA, behavioural and morphological data for the database, and to  
18 facilitate removal of problem individuals. In several places around the world, selective removal of  
19 problem individuals would not be significantly more expensive and definitely less  
20 environmentally-destructive than traditional approaches and would also help reconcile people and  
21 sharks by underlining individuality in shark behaviour.

22

23 **Key words:** human-wildlife conflict, human fatalities, fatal attack, culling campaigns, problem  
24 individuals, DNA fingerprinting, shark food provisioning, feeding aggregation, carnivore risk  
25 management.

26

27 **INTRODUCTION**

28 Although very rare with an average of <10 human fatalities per year (ISAF 2018), shark bites  
29 generate strong emotional reactions among the public that pressure decision-makers to implement  
30 reactive mitigation strategies (Meeuwig and Ferreira, 2014). Mass shark culling campaigns, such as  
31 those recently implemented in Australia and La Reunion island (Clua and Linnell, 2018), have  
32 been the most common management response to fatal shark bites on humans. These campaigns  
33 have detrimental effects on the status of already threatened species and their effectiveness is  
34 questionable (Ferreti et al., 2015). The few analyses suggesting culling campaigns improve human  
35 safety (e.g. Dudley 1997, Cliff and Dudley 2011) lack controls and show apparent trends that may  
36 simply reflect the natural rarity and stochasticity of fatal bites on humans. Analyses of other  
37 culling campaigns show they do not reduce shark bites. One of the most comprehensive studies  
38 conducted on a shark control programs shows how 4,668 sharks (including 554 tiger sharks  
39 *Galeocerdo cuvier* considered to be the species responsible for lethal bites on surfers) were killed  
40 in Hawaii between 1959 and 1976, with “no measurable effects on the rate of shark fatalities in  
41 Hawaiian waters” (Wetherbee et al., 1994). In this study an average rate of 0.6 fatal ‘attacks’ per  
42 year was recorded before and persisted during the culling, with an increase to 1.4 per year during  
43 the years following the program. An ongoing culling campaign around La Réunion Island (Indian  
44 Ocean), removed 33 bull sharks *Carcharhinus leucas* and 122 tiger sharks *Galeocerdo cuvier*  
45 between March 2018 and December 2019, yet two human fatalities (among a total of five around  
46 the world) were still experienced in January and May 2019, respectively (IR 2020).

47  
48 Compared to the very few fatal bites, on a global basis there are hundreds of non-lethal shark bites  
49 on humans, most of them unreported, perpetrated by many shark species potentially driven by  
50 many different motivations including self-defense (Balbridge 1988; Gruber, 1988), territoriality,  
51 hunger or competition (Johnson and Nelson 1973; Gruber, 1988; Jublier and Clua, 2018) or

52 misidentification of prey (Clua, 2018). However, these agonistic behaviours usually only cause  
53 non-fatal superficial wounds and do not trigger the initiation of unselective culling campaigns and  
54 are therefore not the priority focus of our discussion. Instead, we are focusing on fatal or near-fatal  
55 bites that probably result from feeding attempts by larger species (Clua and Reid, 2018). Three  
56 shark species (white shark *Carcharodon carcharias*, tiger shark and bull shark *Carcharhinus*  
57 *leucas* collectively account for most of the worlds' serious and fatal shark bite incidents (ISAF,  
58 2020). The first two species are considered highly migratory (Bonfil et al. 2005; Meyer et al.,  
59 2009), an ecological trait that could partially explain why blind mass culling campaigns, that are  
60 based on a simple density-dependent hypothesis, often fail because they do not remove the very  
61 few animals within the population that constitute a potential threat to humans. This mass predator  
62 culling approach is completely at odds with methods used in terrestrial settings where  
63 considerable efforts are made to carefully identify and selectively remove only problem  
64 individuals associated with negative interactions with humans (Linnell et al., 1999; Packer et al.,  
65 2019), and there is no *a priori* reason why this selective approach cannot be extended to sharks  
66 (Clua and Linnell, 2018).

67  
68 Shark bites on humans are very rare, hence the numbers of sharks biting people must be very low  
69 (i.e. it cannot exceed the number of people bitten). However, these rare incidents often cluster in  
70 space and time, making it possible that a few individual sharks are responsible for multiple bites,  
71 as was recently concluded in Cocos island (Costa Rica), where a 3.5 m Total Length (TL) female  
72 tiger shark was responsible for a fatal bite on a US diver in November 2017, a non-fatal bite on a  
73 German diver in April 2018 and subsequent aggressive interactions with divers (EC Pers. Obs.).  
74 Forensic analyses indicate a 2.5m TL bull shark was responsible for four out of eight shark bite  
75 incidents occurring around La Reunion island (Indian Ocean) between April 2015 and February  
76 2018 (IR, 2020). Neither of these case studies alone can prove or disprove either of the competing

77 hypotheses behind shark fatalities. However, they do illustrate that, compared to usual  
78 environmentally-based drivers of shark bites (Chapman and McPhee 2016), the behavioral  
79 hypothesis (Clua and Linnell, 2018) is an equally, or even more, plausible explanation of the  
80 events, and that it therefore deserves due consideration. This hypothesis states that some animals  
81 with specific behaviors (including boldness and aggressiveness) may potentially pose a higher risk  
82 than conspecifics. Under this scenario the risk of a shark attack in a given area would relate to the  
83 presence of a limited number of high-risk individuals rather than for example shark density or  
84 habitat parameters. Such hypothesis should not be confused with the controversial ‘rogue’ shark  
85 hypothesis (Neff, 2015). While our ‘problem individual’ and a ‘rogue’ shark would both tend to  
86 repeat strikes on human beings, as potential prey, in our perspective, the latter would develop an  
87 aggressive and targeted preference for humans as embodied by films such as “Jaws”. It would also  
88 imply a high degree of individual aggression, whereas the current ethology literature on which we  
89 base our hypothesis underlines individual differences along a shyness-boldness gradient (Clua and  
90 Linnell, 2019). As a matter of fact, given the conservation status and ecological importance of  
91 sharks, there is currently not enough convincing scientific basis for mass unselective culling  
92 campaigns which may completely fail to capture the “problem individual” while simultaneously  
93 inflicting damage on the marine ecosystem.

94  
95 Thus far, alternative strategies and possible improvements to large scale and non-selective shark  
96 culling include (i) in-depth analysis of available attack data to uncover spatio-temporal patterns of  
97 attacks and inform management strategies to enhance public safety and risk perception (Sprivulis,  
98 2014; Ferreti et al., 2015), (ii) the improvement of beach safety with smart drumlines (Guyomard  
99 et al. 2019), nets and/or shark spotters (Curtis et al., 2012), (iii) the use of telemetry protocols to  
100 set up warning systems (Hammerschlag et al., 2011; Curtis et al., 2012; Meeuwig and Ferraira,  
101 2014; McAuley et al., 2016), (iv) the development of effective shark personal or barrier deterrents

102 or repellents (Huveneers et al., 2013; Huveneers et al., 2018; O’Connell et al., 2014; O’Connell et  
103 al., 2018; Stroud et al., 2014), (v) the use by sea users of novel fabrics to resist punctures and  
104 lacerations from large sharks (Whitmarsch et al. 2019), and vi) the enhancement of first aid skills  
105 among the public and first responders for the efficient medical care of shark attack victims (Curtis  
106 et al., 2012). In the case of beach nets that were thoroughly documented in South Africa, such  
107 strategies might appear effective but are economically expensive (US\$ 7 million per annum) and  
108 also have an ecological cost in terms of dead sharks and other by-catches resulting from  
109 entanglement (see Cliff and Dudley, 2011), which appears less and less acceptable to a large  
110 portion of our societies (Swan et al., 2017). None of these strategies consider whether the  
111 identification and selective removal of problem individuals would provide an effective alternative  
112 way to prevent shark attack outbreaks with minimal ecological cost.

113

114 In this paper, we propose a new approach for increasing ocean-users’ safety that is based on  
115 improved forensic analysis for individual shark profiling, combined with existing or new  
116 underwater studies to identify individual sharks in order to selectively remove the ‘problem’  
117 animals after the confirmation of their involvement in a human fatality. This approach has the  
118 potential to reduce the negative ecological effects currently posed by non-selective shark culling  
119 campaigns, and to alleviate the conflicts with stakeholders opposed to them.

120

## 121 **PROFILING OF “PROBLEM INDIVIDUALS” AFTER A BITE ON HUMANS**

122

123 In practice, the success of management approaches based on selective shark removal will depend  
124 on the development of protocols that enable the reliable identification and targeted removal of  
125 ‘problem individuals’ (Linnell et al., 1999; Swan et al., 2017). To significantly improve the  
126 management of these events in a given area, we propose to (i) improve the speed and effectiveness

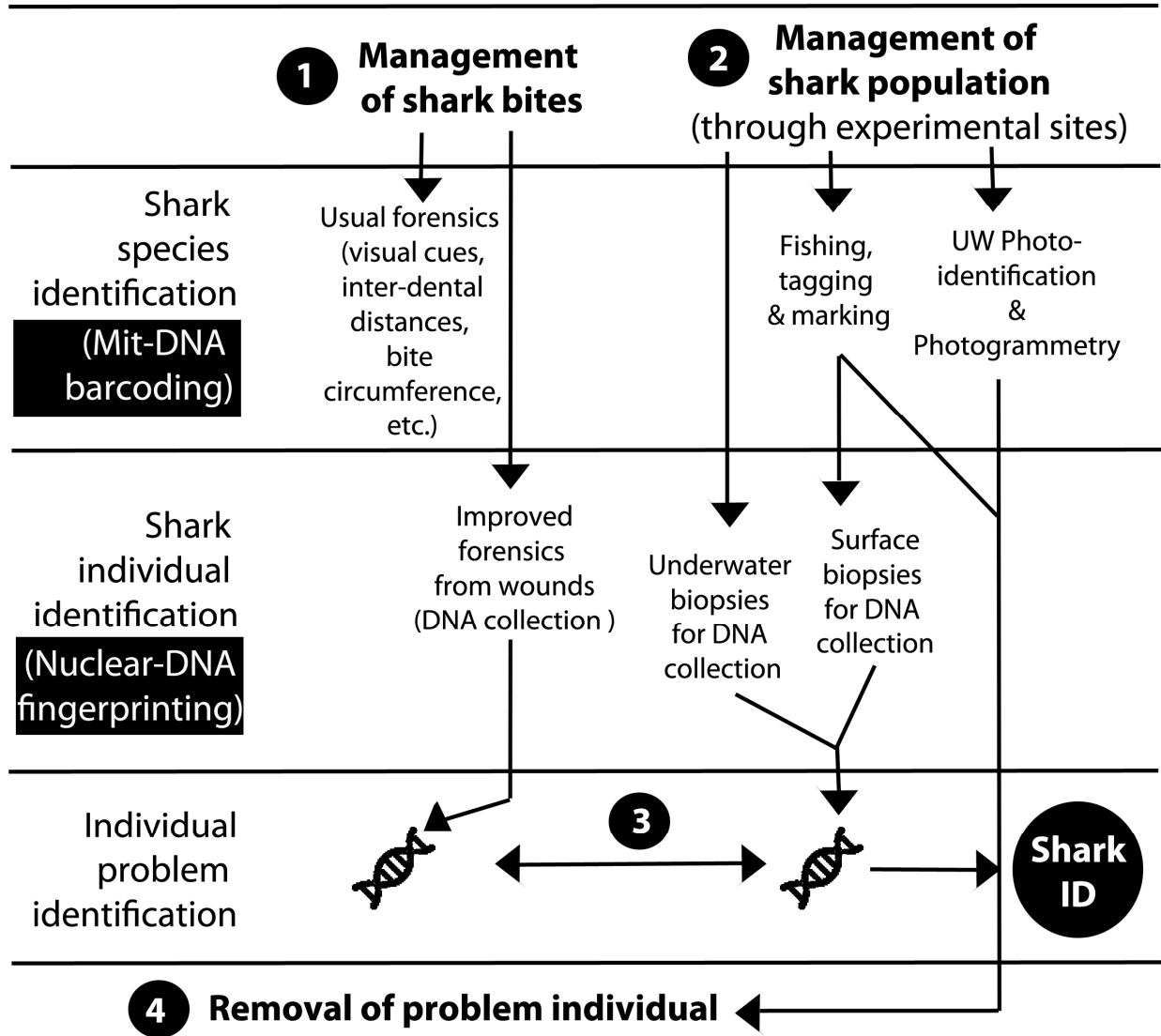
127 of forensic analysis that follows a shark fatality to profile the problem animals and, (ii) broaden  
128 the access to sharks in order to set up a database of sharks against which to compare DNA  
129 recovered from shark bite incidents and to access the animals to individually identify them and to  
130 manage the risk. This database could be compiled from innovative shark aggregating and/or  
131 existing mark-release fishing operations.

132  
133 Although we already have several forensic techniques already available for identifying the species  
134 and size of shark responsible for bite incidents (Lowrie et al., 2009; Clua and Reid, 2018), these  
135 are not being used consistently and none of them are as precise or definitive as the use of DNA  
136 techniques which hold potential to definitively identify species, sex and the individual responsible  
137 for the incident. For example, Inter-Dental Distance (IDD) measurements and other features of  
138 the wounds, combined with ecological knowledge of the suspected shark species and witness  
139 accounts, can help to accurately profile the incident perpetrator (Lowrie et al., 2009; Clua and  
140 Reid, 2018) (Fig. 1) yet these techniques are not always fully applied.

141  
142 Systematic attempts to accurately profile a shark and recommend appropriate management actions  
143 should be undertaken as soon as possible (within a few hours, through use of the internet and  
144 based on adequate photographic documentation) after the incident. The victim and associated  
145 accessories (e.g. surfboard, wetsuit) should be swabbed for transfer DNA as soon as possible after  
146 the bite occurs. Ocean lifeguards and other emergency personnel could be issued simple swab kits  
147 to collect samples from accessories at the beach, or medical personnel could swab wounds once  
148 the patient has been stabilized. DNA barcoding to identify the shark species involved in the  
149 incident is easy and inexpensive with readily available primers (Fields et al., 2015) and studies  
150 have demonstrated that it works with DNA collected from flesh (Fotedar et al., 2019). However,  
151 as a first step forward for managing fatal bites, DNA fingerprinting using microsatellite repeat



152 sequences would allow the identification of an individual among a given species (Chambers et al.,  
 153 2014). DNA barcoding could be skipped if other forensic analysis methods (see above) could  
 154 reliably identify the species of shark (Fig. 1).



155  
 156 **Figure 1** – General management of problem individuals that would rely on (1) the critical step of  
 157 collecting DNA fragments in the framework of an improved forensic analysis following a shark  
 158 strike on a human, (2) the parallel setting up of a genetic fingerprinting database of potential  
 159 perpetrators (using experimental aggregation sites or other capture-recapture studies) which is also  
 160 linked to a photographic image database, in order to (3) obtain the match between fingerprints and  
 161 (4) the potential selective removal of a problem individual that would be spotted either on an  
 162 experimental aggregation site again or through a tagging program, locally or at a regional level,

163 days or even months after the strike. NB: Shark DNA could also be collected from personal  
164 accessories such as surfboards following bite incidents.

165

166 **SPOTTING AND PROFILING THE POOL OF POTENTIAL “PROBLEM**  
167 **INDIVIDUALS”**

168

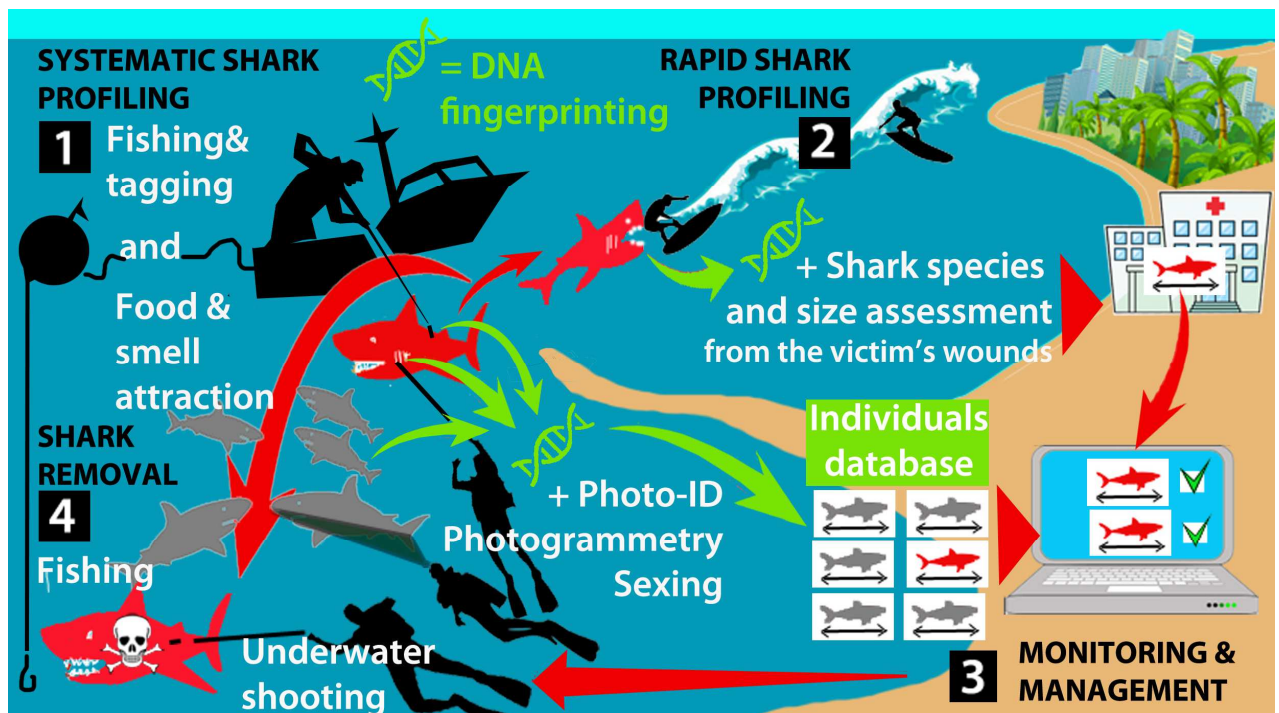
169 Identifying individuals responsible for shark bites is a first critical step but finding them in the  
170 wild still poses a great challenge as large sharks are elusive and mobile animals. We need a library  
171 of DNA samples large enough to include the potential problem individuals within the larger  
172 population and we need a method of rapidly and definitively identifying those sharks in the field if  
173 removal is warranted. We propose a two-fold strategy to achieve this: (1) Leveraging existing  
174 shark tagging programs to obtain DNA profiles from individuals marked with external  
175 identification tags, and (2) Create temporary shark aggregation sites by using attractants (bait,  
176 blood etc.) in order to photograph (for visual identification purposes) and biopsy attendant sharks.  
177 Shark aggregation techniques are usually used for ecotourism purposes but could easily become  
178 management tools for profiling and removing problem individuals (Fig. 2). Individual  
179 identification among species with polymorphic color patterns such as those found on white and  
180 tiger sharks is effective and has proven to be reliable (Domeier and Nasby-Lucas, 2006). While  
181 more complicated, individual identification is also possible for those with uniform color patterns  
182 such as the bull shark (Brunnschweiller and Barnett, 2013). Problem animals could be ideally  
183 identified through genetics (by crossing the DNA fingerprinting results of forensics and  
184 underwater DNA sampling).

185 Such observation and management (sampling and occasional removal) sites could be implemented  
186 in remote and confined areas, for example offshore where ocean users are not likely to be  
187 accidentally involved. However, these areas would need to be sufficiently spatially connected to

188 sites, like popular swimming or surfing beaches, where protection is essential. As a point to  
 189 support the strong attractiveness of these artificial provisioning sites as compared to the locations  
 190 of traditional fishing removal sites, acoustic-tagged bull sharks that were aggregated at a feeding  
 191 site in Fiji were locally detected regardless of whether it was a feeding or a non-feeding day  
 192 (Brunnschweiler and Barnett, 2013). Given the strong attractiveness of odor stimuli, we strongly  
 193 believe that such experimental sites would provide suitable access to both transient animals, such  
 194 as white and tiger sharks that are known for their high mobility and more resident species like bull  
 195 sharks.

196 This two-fold approach based on fishing and/or diving appears necessary as (i) not all regions  
 197 allow shark chumming, (ii) mark-recapture fishing can sample much more extensive areas than the  
 198 aggregation method.

199



200

201 **Figure 2** – Schematic representation of the proposed management system for managing shark  
 202 fatalities. 1: Systematic and large-scale shark profiling should be undertaken through existing  
 203 fishing-based capture-recapture operations and/or artificial provisioning sites that would be

204 organized in a remote (offshore) site at a suitable distance from exposed beaches in order to  
205 aggregate all large sharks potentially dangerous for humans. In both approaches, systematic DNA  
206 sampling would be conducted for individual fingerprinting. This individual genetic profiling  
207 would be complemented by any means allowing the identification of the shark afterwards such as  
208 tagging and photo-identification, including for photogrammetry (with calibrated lasers) performed  
209 by expert scuba-divers allowing an accurate individual identification of sharks, whatever their  
210 species. The objective is for any shark to be individually identifiable for removal. A local  
211 database of individual sharks would be maintained, possibly enriched by data from other sites and  
212 countries. 2: Any incident with humans would be followed by a quick and efficient forensic  
213 process aiming at collecting DNA fragments in the victim's wounds and assessing the shark  
214 species and length whenever possible. In an ideal scenario, a DNA fingerprinting analysis would  
215 allow the identification of the problem individual. 3: The information (species, size and individual  
216 DNA identity) would be crossed with the local database of sharks potentially dangerous for  
217 humans. A match would designate the identity of the shark involved in the incident. 4: Based on  
218 full (through DNA identification) or basic (through only species and length assessment) profiling,  
219 the (few) potential candidate(s) would be removed either through a fishing process or an  
220 underwater shooting. This approach would also work with a transient shark that never came to the  
221 observation site before causing a human fatality. Such a shark could be DNA sampled at the  
222 neighboring aggregation site (or another one) after the incident and still be removed if it is spotted  
223 again after being positively identified as a problem individual.

224

225 **LARGE-SCALE REGIONAL COOPERATION FOR MANAGING MIGRATORY**  
226 **SPECIES**

227

228 Two studies have shown a relatively high site fidelity of satellite-tagged bull sharks and tiger  
229 sharks that have moved over hundreds of kilometers in the Pacific (Brunnschweiler et al., 2010)  
230 and thousands of kms in the Western Atlantic (Hammerschlag et al., 2012), respectively, before  
231 returning to artificial provisioning sites. Such information supports the utility of setting up a  
232 genetic database based on aggregation sites. However, the highly migratory behaviour of some  
233 individuals poses two main problems for our proposed method. Firstly, an unknown, unsampled  
234 and therefore unidentifiable transient shark could bite someone. Secondly, a known shark  
235 considered locally resident could bite someone and then leave the area. This could be overcome by  
236 creating a regional database of individual genetic profiles, identification photos and tags from  
237 potentially dangerous species. This database could be consulted whenever DNA is recovered from  
238 a shark bite incident in order to allow the identification of locally-unknown problem individuals.  
239 Following conclusive identification, the removal of the animal could then happen in a different  
240 place and at a different time, including several months after a shark incident, including fatal but  
241 also serious non-fatal bites.

242

243 **PUBLIC ACCEPTANCE AND SAFETY CONCERNS REGARDING THE FEEDING**  
244 **SITES**

245

246 The potential deleterious effects of such artificial food provisioning (see Brena et al., 2016) appear  
247 as a more acceptable ecological risk than the large-scale non-selective culling of threatened  
248 animals. Unlike for terrestrial predators such as bears (Floyd, 1999), it has never been shown that  
249 such artificial provisioning with the associated risks of food conditioning increase the risk of  
250 human fatalities in the vicinity of the activity. Empirical data from a feeding site set up in the  
251 1990s' in Fiji and involving more than 50 bull sharks (considered as a potentially dangerous shark  
252 species for humans) has had no incidents in 28 years, in spite of many ocean users (in addition to

253 scuba divers) being in the vicinity of the feeding spot on a daily basis (M. Neumann, Pers.  
254 Comm.). Beside the example of Fiji, figures show that other places where artificial provisioning is  
255 usually implemented (without culling) such as Tahiti (French Polynesia), Playa del Carmen  
256 (Mexico) or Tiger beach (Bahamas) have a very low rate of (if any) shark fatalities whereas places  
257 with no feeding activities (and regular blind fishing campaigns) such as Western Australia, Brazil  
258 or La Reunion account for the most human fatalities (ISAF, 2020). Furthermore, such a scientific  
259 framework would only involve a few expert divers with controlled procedures to decrease the link  
260 that animals may make between feeding stimuli and humans.

261

262 **SCIENTIFIC MONITORING OF SHARK MOVEMENTS AND BEHAVIOR TO**  
263 **PREVENT ATTACKS**

264

265 With the exception of ending the non-selective culling campaigns, our proposal for selective  
266 management through individual shark profiling does not aim, at least in the short term, to replace  
267 the traditional management measures for shark attack mitigation. Those involving the VR4  
268 receivers that are able to spot an acoustic tag on a given shark as implemented in south-western  
269 Australia (McAuley et al., 2016), would actually be very complementary to the individual  
270 profiling approach. The monitoring of feeding sites could be used, not only for photo-ID, sizing  
271 and DNA sampling, but also for acoustic tagging of the sharks. The acoustic arrays would then  
272 provide valuable information about shark movements, including locating forensically-identified  
273 problem individuals; the presence of such an animal in the vicinity of a populated beach properly  
274 equipped with VR4 receivers could constitute a high level of risk with a proportionate response  
275 through a management risk protocol, such as a temporary beach closure. Such a process would  
276 ease the short-term risk from this individual, before it was selectively removed. Furthermore,  
277 studies of individual shark behaviour (i.e. boldness or aggression) at aggregation sites over time,

278 and with links to investigation of non-fatal bites or aggressive approaches (using DNA and/or  
279 photographic approaches) could be used to increase knowledge of behavioural individuality in  
280 sharks, and potentially develop protocols for pre-emptive removal of individuals with risky  
281 behaviour.

282

### 283 **COST-EFFECTIVENESS IN COMPARISON TO CURRENT PRACTICES**

284

285 The Hawaii shark culling programme (from 1956 to 1974) came up with an average cost of  
286 US\$182 per shark killed. If we use the 1969 inflation rate as the reference date, the cost in 2019  
287 per shark culled would be US\$1,228 for a total expense of US\$2,123,095 to kill 4,668 sharks and  
288 without a detectable impact on shark bite numbers (Wetherbee et al., 1994). In fact, two shark  
289 bites occurred right toward the end, and immediately after, the largest culling program (1967-  
290 1969). One of those bites occurred at a beach from where 33 tiger sharks had been culled (CM  
291 Pers. Comm.). In March 2018, the French Ministry of Oversea Territories declared an increase in  
292 the government subsidies to La Reunion island up to US\$2,200,000 per year for shark crisis  
293 management (Outremer 2018). Among the global budget involving several prevention actions, a  
294 US\$660,000 culling campaigns allowed the removal of 80 (65 tiger and 15 bull) sharks, i.e.  
295 US\$8,250 per shark culled, while two fatal bite still took place in January and May 2019 (IR,  
296 2020). Once genetic reference databases already exist for the three main targeted shark species, a  
297 continuing fingerprinting analysis (involving an average of 20-loci as we suggest it) would cost  
298 US\$40-50 per shark. The exhaustive genetic referencing of the bull shark population of a place  
299 like La Reunion island, which would include a maximum of 1,200 individuals as estimated by the  
300 CHARC project (2015), would then cost < US\$660,000 over several years, probably not involving  
301 (much) more running costs than present activity in terms of operations aiming at collecting shark  
302 DNA. The surface fishing operations are already implemented and funded (<30% of the total

303 yearly amount dedicated to the shark crisis management of US\$2,200,000 per year); they could be  
304 maintained but instead of culling shark, they could focus on DNA sampling. The complementary  
305 underwater operations suggested in this paper may indeed represent an extra and significant cost;  
306 but given what is at stake, it should be arbitrated with other significant expenses that are made  
307 with likely limited direct impact on public safety, such as a 3-D sonar with a 165-m range for  
308 shark detection on a single beach that cost US\$770,000 for setting up in 2019 with an average  
309 running cost of US\$375,000 per year (Anonymous 2019). Based on these figures, the potential of  
310 gaining more efficiency in terms of public safety while sparing the lives of hundreds of sharks,  
311 should not be jeopardized based on financial arguments. In addition, these genetic databases could  
312 be used for other scientific purposes (such as the monitoring the genetic diversity or population  
313 trends for a given species) in addition to identifying a problem individual.

314

## 315 **CONCLUSIONS**

316

317 Although our management perspective does not resolve the issue of the mechanism behind shark  
318 incidents it offers more effective (in terms of improving human safety) and less ecologically  
319 damaging responses to these incidents. Furthermore, focusing management on individual animals  
320 would take the blame away from sharks in general and could help to improve the reputation of  
321 sharks worldwide (Swan et al., 2017).

322

## 323 **Conflict of interest**

324 None

325

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