Matters arising

Shark mortality cannot be assessed by fishery overlap alone

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ARISING FROM N. Queiroz et al. *Nature* https://doi.org/10.1038/s41586-019-1444-4 (2019)

Many shark species worldwide are vulnerable to overexploitation due to fishing. Using only the horizontal spatial overlap between the space use of 23 satellite-tracked shark species and the fishing distribution of pelagic longline fisheries tracked using an automatic identification system, Queiroz et al.[1] concluded that sharks are at high risk when substantial horizontal overlap occurs. This approach to estimate fishing susceptibility, coupled with limited tag-based shark distributions to estimate fishing exposure index (FEI) hotspots, severely limits their findings and, therefore, conclusions.

We challenge several assumptions made by the authors and argue that horizontal overlap alone is an unreliable indicator of susceptibility because other factors contribute considerably to catch risk, as shown

Table 1 | Linear regressions between North Atlantic annual shark landings and shark FEI

Change from original	Data	Annual average	Landings	Species	*P* value	*F*	d.f.	Adjusted R^2
Queiroz et al.[1]	2007–2016	Positive values only	log scale	Eight species, hammerhead sharks included *S. zygaena*, *S. mokarran*, *S. lewini*	0.0374[a]	7.089	6	0.46
Landings averaged over the whole period	2007–2016	All time series	log scale	Same species as in Queiroz et al.[1]	0.0519	5.854	6	0.41
Landings computed for 2012–2016	2012–2016	Positive values only	log scale	Same as Queiroz et al.[1]	0.1883	2.318	5	0.18
Landings computed for 2012–2016 and averaged over the whole period	2012–2016	All time series	log scale	Same as Queiroz et al.[1]	0.2059	2.112	5	0.1563
Including not-identified hammerhead landings as hammerhead sharks	2007–2016	Positive values only	log scale	Including hammerhead sharks not identified as hammerhead sharks	0.1139	3.42	6	0.2569
Including not-identified hammerhead landings as hammerhead sharks and averaged over the whole period	2007–2016	All time series	log scale	Including hammerhead NEI as hammerhead sharks	0.1288	3.1	6	0.2308
Including not-identified hammerhead landings as hammerhead sharks and landings computed for 2012–2016	2012–2016	Positive values only	log scale	Including hammerhead NEI as hammerhead sharks	0.3605	1.013	5	0.0021
Including not-identified hammerhead landings as hammerhead sharks and landings computed for 2012–2016 averaged over the whole period	2012–2016	All time series	log scale	Including hammerhead NEI as hammerhead sharks	0.3782	0.9341	5	−0.0011
Absolute landings instead of in log scale	2007–2016	Positive values only	Absolute	Same as Queiroz et al.[1]	0.1676	2.463	6	0.1729
Absolute landings instead of in log scale and including not-identified hammerhead landings as hammerhead sharks	2007–2016	Positive values only	Absolute	Including hammerhead nei as hammerhead sharks	0.1812	2.287	6	0.1553

Landings from FAO total capture production (http://www.fao.org/fishery/statistics/global-capture-production/query/es) and shark FEI were calculated as described in Queiroz et al.[1]. 'Change from original' describes the changes from the original relationship in Queiroz et al.[1]: (i) using all years to average the annual landings instead of only using the positive values as in Queiroz et al.[1], to account for zero catches; (ii) using data from 2012–2016 for which fishing effort data from the automatic identification system were available for estimating the average annual landings; and (iii) including *Sphyrna* spp. and/or hammerhead NEI in the hammerhead group because they may comprise *S. zygaena*, *S. mokarran* or *S. lewini*. NEI, not otherwise identified.

[a]*P* value was statistically significant at the 5% level of significance.

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Table 2 | Contingency tables between FEI hotspots, fishing effort hotspots and shark-density hotspots for EEZ, ABNJ and globally

FEI hotspots	**Fishing effort hotspots (EEZ data)**			**Fishing effort hotspots (ABNJ data)**			**Fishing effort hotspots (global scale)**		
	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total
Positive	147	225	372	234	229	463	381	454	835
Negative	1,439	7,246	8,685	2,364	10,476	12,840	3,803	17,722	21,525
Total	1,586	7,471	9,057	2,598	10,705	13,303	4,184	18,176	22,360
Sensitivity or true-positive rate (95% CI)	9% (8–11%)			9% (8–10%)			9% (8–10%)		
Positive predictive value or precision (95% CI)	40% (35–45%)			51% (46–55%)			46% (42–49%)		
Statistical test	$\chi^2 = 128.46$, d.f. = 1, $P < 2.2 \times 10^{-16}$			$\chi^2 = 291.49$, d.f. = 1, $P < 2.2 \times 10^{-16}$			$\chi^2 = 411.32$, d.f. = 1, $P < 2.2 \times 10^{-16}$		
Shark-density hotspots	**Fishing effort hotspots (EEZ data)**			**Fishing effort hotspots (ABNJ data)**			**Fishing effort hotspots (global scale)**		
	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total
Positive	78	1,132	1,210	94	1,010	1,104	172	2,142	2,314
Negative	1,508	6,339	7,847	2,504	9,695	12,199	4,012	16,034	20,046
Total	1,586	7,471	9,057	2,598	10,705	13,303	4,184	18,176	22,360
Sensitivity or true-positive rate (95% CI)	5% (4–6%)			4% (3–4%)			4% (4–5%)		
Positive predictive value or precision (95% CI)	6% (5–8%)			9% (7–10%)			7% (6–9%)		
Statistical test	$\chi^2 = 117.49$, d.f. = 1, $P < 2.2 \times 10^{-16}$			$\chi^2 = 92.183$, d.f. = 1, $P < 2.2 \times 10^{-16}$			$\chi^2 = 215.05$, d.f. = 1, $P < 2.2 \times 10^{-16}$		
FEI hotspots	**Shark-density hotspots (EEZ data)**			**Shark-density hotspots (ABNJ data)**			**Shark-density hotspots (global scale)**		
	Positive	Negative	Total	Positive	Negative	Total	Positive	Negative	Total
Positive	238	134	372	211	252	463	449	386	835
Negative	972	7,713	8,685	893	11,947	12,840	1,865	19,660	21,525
Total	1,210	7,847	9,057	1,104	12,199	13,303	2,314	20,046	22,360
Sensitivity or true-positive rate (95% CI)	20% (17–22%)			19% (17–22%)			19% (18–21%)		
Positive predictive value or precision (95% CI)	64% (59–69%)			46% (41–50%)			54% (50–57%)		
Statistical test	$\chi^2 = 128.46$, d.f. = 1, $P < 2.2 \times 10^{-16}$			$\chi^2 = 870.66$, d.f. = 1, $P < 2.2 \times 10^{-16}$			$\chi^2 = 1758$, d.f. = 1, $P < 2.2 \times 10^{-16}$		

Hotspots are defined by cells with ≥75th percentile of FEI, shark relative density or fishing effort as described in Queiroz et al.[1]. Data were obtained from (https://github.com/GlobalSharkMovement/GlobalSpatialRisk). Top, FEI hotspots match with fishing effort hotspots in only 40%, 51% and 46% of cases in EEZs, ABNJs and at the global scale, respectively; whereas the true-positive rate for which FEI correctly identifies a fishing effort hotspot is 9% in all cases. Middle, shark relative density hotspots match with fishing effort hotspots in only 6%, 9% and 7% of the cases in EEZs, ABNJs and at the global scale, respectively, whereas the true-positive rate is about 5%. Bottom, FEI hotspots match shark relative density hotspots in 64%, 46% and 54% of cases in EEZs, ABNJs and at the global scale, respectively; whereas the true-positive rate is around 20%. 95% CI, 95% confidence interval.

by well-established ecological risk assessment methods[2,3]. Moreover, we consider that the locations of FEI hotspots are biased towards areas for which tagging data are available. These limitations may misdirect urgent management actions that are needed to mitigate—globally and holistically—true fishing risks for sharks in all ocean regions. Our criticisms comprise the four main points below.

First, horizontal overlap does not provide a robust risk estimate. The two-dimensional horizontal overlap between the distribution of a species and fishing effort (that is, 'availability') is only one component of susceptibility explaining risk[4], which also includes encounterability, selectivity and post-capture mortality. Encounterability is the potential for a species to interact with fishing gear within its depth range. Selectivity is the propensity for an organism to be caught once it encounters the fishing gear[4]. For example, even with 100% horizontal overlap between the distribution of a mesopelagic shark and a surface pole-and-line fishery, encounterability and selectivity are negligible, and thus the species would have low catchability and risk. The species asessed by Queiroz et al.[1] occupy different depth ranges and undergo diel vertical migrations[5,6] that result in different encounterability[7]; however, this was not considered. Furthermore, shark species have different life-history traits, behaviours and mouth morphologies that differentially affect their selectivity to baited longline hooks[8,9], which should also be included in risk assessments.

Current handling and release practices can reduce at-vessel and post-release mortality[10]. For example, at-vessel and post-release survival of pelagic sharks—including the great hammerhead and tiger shark species analysed by Queiroz et al.[1]—ranges from 33% to 100%[6,11]; information that was also omitted from the risk estimation of Queiroz et al.[1].

Widely used ecological risk assessments[2,3] include all susceptibility (and productivity) components[3] to estimate risk. Therefore, risk may not necessarily be high with high horizontal overlap if encounterability, selectivity and/or post-capture mortality is low (for example, for tiger sharks[7,9]).

Second, the fishing exposure index (FEI) developed by Queiroz et al.[1]—relative shark density multiplied by fishing effort—is not a robust proxy for fishing-induced shark mortality as it is fundamentally another measure of geospatial overlap. The authors claim that FEI "reflects fishing-induced shark mortality" based on a linear relationship between FAO landings data for the North Atlantic and FEI values for eight shark species (extended data figure 5 of Queiroz et al.[1]). We accessed the FAO statistics, following the authors' description of the data used, to calculate the relationship between shark landings and FEI. We tested different options of (1) landing periods; (2) all versus positive years; and (3) including non-identified hammerhead landings as hammerhead landings, and found no significant relationships ($P > 0.1$) in all combinations, except the single case cited by Queiroz et al.[1] (Table 1). Moreover, the relationship between FEI and catch including all species does not reflect fishing mortality, unless the abundance of each species is the same (catch = fishing mortality × abundance), which is not the case. For example, if abundance is low—as for white sharks—even low catches could reflect high fishing mortality and, vice versa, high catches could indicate higher shark abundance but not necessarily higher fishing mortality. Thus, FEI is not a reliable proxy for fishing-induced shark mortality. Because the conclusions of Queiroz et al.[1] hinge on FEI representing risk and fishing mortality, their conclusions lack support.

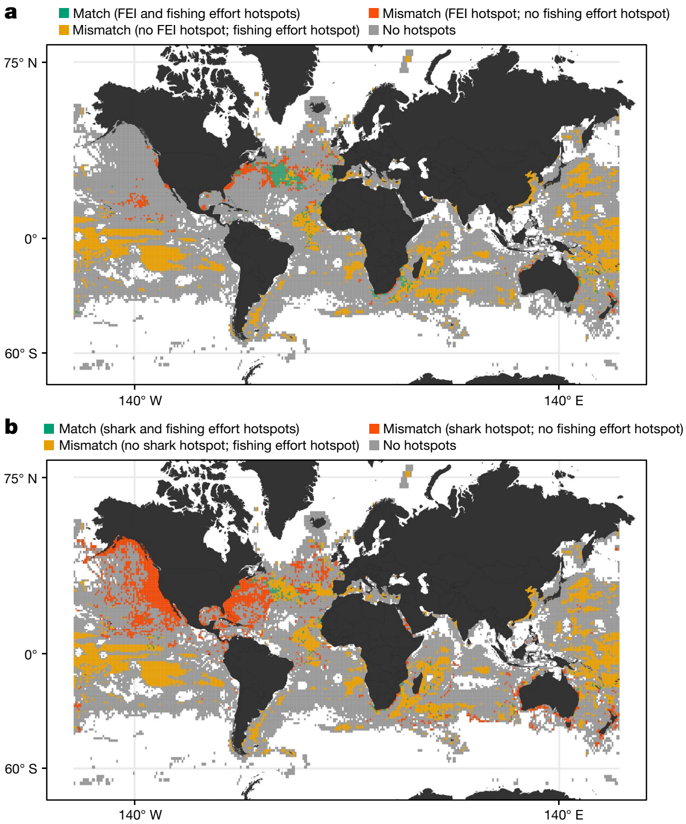

Fig. 1 | Match or mismatch between FEI hotspots or shark density hotspots, and fishing effort hotspots. a, b, Match or mismatch between FEI hotspots and fishing effort hotspots (**a**) and match or mismatch between shark relative density hotspots and fishing effort hotspots (**b**). Green points indicate that there is a match between FEI or shark relative density hotspots and fishing effort hotspots grids. Red points indicate mismatched grids of FEI or shark relative density hotspots with no fishing effort hotspots. Orange points indicate mismatched grids of fishing effort hotspots with no FEI or shark relative density hotspots. Grey points indicate grids with no hotspots for both FEI or shark relative density and fishing effort. The figure was created using R software[16].

Third, the use of 'exposure risk plots' between spatial overlap and FEI by species using the mean overlap and mean FEI across all species in a region as a reference point to delineate risk is misleading. High risk (red quadrants in figure 3 of Queiroz et al.[1]) means that the risk of a species is above average, which may occur when exposure risk is low (for example, blue shark (*Prionace glauca*), eastern Pacific; great white shark (*Carcharodon carcharias*), Oceania). Worryingly, high-risk species can be considered low risk in a region if most sharks show high overlap and FEI.

Moreover, based on FEI hotspots, Queiroz et al.[1] concluded that "high fishing effort is focused on extensive shark hotspots globally". We disagree as there is a significant mismatch between FEI hotspots and shark density hotspots and fishing effort hotspots (Table 2), revealing that shark hotspots are not related to main fishing effort areas (Fig. 1b). For example, the true-positive rate when FEI hotspots correctly identifies a fishing effort hotspot is 9% (Table 2). Furthermore, using their methodology, FEI hotspots cannot be identified in regions for which no fishing data from the automatic identification system are available (for example, neritic regions within Exclusive Economic Zones (EEZs)) or in areas with no shark tagging information (Fig. 1).

Finally, although the size of grid cells did not affect species risk exposure plots and species occurrence within the high- or low-risk zones, the absolute values of overlap and FEI are greatly affected by grid cell size. Supplementary table 9 of Queiroz et al.[1] shows that the mean overlap decreased from 21.6% at a resolution of $1° \times 1°$ to 5.03% overlap using a resolution of $0.10° \times 0.10°$, whereas FEI decreased from 3.0×10^{-5} to 3.9×10^{-8}, respectively. The concomitantly large decrease in overlap and FEI may therefore affect FEI hotspots and, thus, compromise the results of Queiroz et al.[1].

Queiroz et al.[1] concluded that limited spatial refuges for sharks exist in Areas Beyond National Jurisdictions (ABNJs). Of the total FEIs in their data (https://github.com/GlobalSharkMovement/GlobalSpatialRisk), 36% and 64% lie in ABNJs and EEZs, respectively. Furthermore, 56% of ABNJs (7,856 km^2) and 67% of EEZs (8,325 km^2) have FEI values of zero, thus clearly identifying possible refuge areas (Fig. 1). Although Queiroz et al.[1] underestimate refugia due to limited tagging, their results do not support the conclusion of "limited spatial refuge" in ABNJs.

To conclude, we agree with Queiroz et al.[1] about the need for improved conservation and management measures for sharks as mounting evidence suggests that their populations are being subjected to increasing pressure globally by fishing[12]. We also agree that 'industrial' pelagic fisheries have an important role in these impacts, but note that regional fishery management organizations for tuna have made some progress by adopting several shark non-retention and mitigation management measures[13]. There is also growing evidence[14] that the fleet size and impact of the often less regulated and monitored artisanal coastal fisheries—which primarily use longlines and gillnets—can be as large as those of industrial fleets that fish the ABNJs[15]. The magnitude of total shark catches by these fisheries must be better understood to determine the true global risk for sharks.

The analysis by Queiroz et al.[1] defines risk based only on horizontal overlap, equates FEI to fishing mortality and estimates FEI only on the basis of areas for which shark tagging data are available. It therefore identifies FEI hotspots that are not necessarily the areas in which sharks are at greatest risk from fishing. Therefore, using the hotspots identified by Queiroz et al.[1] to define spatial management measures may not only focus protection in sub-optimal areas, but could also detract from management efforts across 100% of shark distributions to mitigate mortality by reducing fishery encounterability, selectivity and post-capture mortality. Such management approaches, in collaboration with regional fishery management organizations for tuna and small-scale fleets, are essential to achieving meaningful reductions in risks from fishing for sharks.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this paper.

Data availability

To prepare Table 1 and linear regressions between North Atlantic annual shark landings (FAO total capture production) and shark FEI as calculated by Queiroz et al.[1], FAO statistics available from http://www.fao.org/fishery/statistics/global-capture-production/query/es were used following the description of the data by Queiroz et al.[1]. To produce Table 2 and Fig. 1, data from Queiroz et al.[1] were used from https://github.com/GlobalSharkMovement/GlobalSpatialRisk.

1. Queiroz, N. et al. Global spatial risk assessment of sharks under the footprint of fisheries. *Nature* **572**, 461–466 (2019).
2. Hobday, A. J. et al. Ecological risk assessment for the effects of fishing. *Fish. Res.* **108**, 372–384 (2011).
3. Gallagher, A. J., Kyne, P. M. & Hammerschlag, N. Ecological risk assessment and its application to elasmobranch conservation and management. *J. Fish Biol.* **80**, 1727–1748 (2012).
4. Hilborn, R. & Walters, C. J. *Quantitative Fisheries Stock Assessment, Choice, Dynamics and Uncertainty* (Chapman and Hall, 1992).
5. Weng, K. C. & Block, B. A. Diel vertical migration of the bigeye thresher shark (*Alopias superciliosus*), a species possessing orbital retia mirabilia. *Fish Bull.* **102**, 221–229 (2004).
6. Queiroz, N., Humphries, N. E., Noble, L. R., Santos, A. M. & Sims, D. W. Short-term movements and diving behaviour of satellite-tracked blue sharks *Prionace glauca* in the northeastern Atlantic Ocean. *Mar. Ecol. Prog. Ser.* **406**, 265–279 (2010).

7. Cortés, E. et al. Expanded ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Collect. Vol. Sci. Pap. ICCAT* **71**, 2637–2688 (2015).
8. Foster, D. G., Epperly, S. P., Shah, A. K. & Watson, J. W. Evaluation of hook and bait type on the catch rates in the Western North Atlantic Ocean pelagic longline fishery. *Bull. Mar. Sci*. **88**, 529–545 (2012).
9. Cortés, E. et al. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquat. Living Resour*. **23**, 25–34 (2010).
10. Ellis, J. R., McCully Phillips, S. R. & Poisson, F. A review of capture and post-release mortality of elasmobranchs. *J. Fish Biol*. **90**, 653–722 (2017).
11. Gallagher, A. J., Orbesen, E. S., Hammerschlag, N. & Serafy, J. E. Vulnerability of oceanic sharks as pelagic longline bycatch. *Glob. Ecol. Conserv*. **1**, 50–59 (2014).
12. Pacoureau, N. et al. Half a century of global decline in oceanic sharks and rays. *Nature* **589**, 567–571 (2021).
13. Poisson, F. et al. Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquat. Living Resour*. **29**, 402 (2016).
14. Doherty, P. D. et al. Big catch, little sharks: insight into Peruvian small-scale longline fisheries. *Ecol. Evol*. **4**, 2375–2383 (2014).
15. Alfaro-Shigueto, J. et al. Where small can have a large impact: structure and characterization of small-scale fisheries in Peru. *Fish. Res*. **106**, 8–17 (2010).
16. R Core Team. *R: A language and environment for statistical computing*. http://www.R-project.org/ (R Foundation for Statistical Computing, 2019).

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Additional information
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