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Shark conservation risks associated with the use of shark liver oil in SARS-CoV-2 vaccine development

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Abstract: The COVID-19 pandemic may create new demand for wildlife-generated products for human health, including a shark-derived ingredient used in some vaccines. Adjuvants are a vaccine component that increases efficacy, and some adjuvants contain squalene, a natural compound derived from shark liver oil which is found most abundantly in deep-sea sharks. In recent decades, there has been growing conservation concern associated with the sustainability of many shark fisheries. The need for a potentially massive number of adjuvant-containing SARS-CoV-2 vaccines may increase global demand for shark-derived squalene, with possible consequences for shark conservation, especially of vulnerable and understudied deep-sea species. A shift to non-animal-derived sources of squalene, which are similar in cost and identical in effectiveness, or an emphasis on increasing traceability and sustainability of shark-derived squalene from existing well-managed fisheries, could better support conservation and public health goals.

Keywords: Squalene, COVID-19, SARS-CoV-2, Shark, Liver oil, Vaccines

1. Introduction

Shark populations have historically been exploited for meat, fins, leather, and products derived from their liver oil, including vitamin A and additives to topical cosmetic formulas and lotions (Dent and Clarke, 2015; Lozano-Grande et al., 2018). Some historic shark liver oil fisheries have been associated with intense, short-lived periods of exploitation contributing to stock collapses (Stevens et al., 2000; Kyne and Simpfendorfer, 2007; Anderson and Waheed, 1999; Ali and Sinan, 2014). Sharks, particularly deep-sea species, tend to grow slowly and produce relatively few young, leaving them especially susceptible to overexploitation (Simpfendorfer and Kyne, 2009). Squalene is a natural polyunsaturated hydrocarbon compound (C₃₀H₅₀) found in many living organisms that can be refined from shark liver oil. This compound (and its more stable, hydrogenated derivative, squalane) have shown genuine potential to contribute to human health, as an ingredient in vaccines and other pharmaceuticals and dietary supplements (Kim and Karadeniz, 2012).

Many shark species, particularly deep-sea sharks, have relatively large livers (up to 20% of animal weight) which serve as a buoyancy control system and critical energy reserve (Vannuccini 1999; Abel and Grubbs 2020). A significant portion of liver weight is made up of

liver oil (10-70%; Nichols et al., 2001), and between 15 and 82% of liver oil is squalene (Deprez et al., 1990; Bakes & Nichols 1995). Although squalene is produced by a range of animals and plants, shark liver oil has historically been a preferred commercial source based on availability and high yields relative to most plant-derived sources.

Squalene can be extracted directly from shark liver oil at high purity (>98%) in approximately 10 hours, using a single distillation process in a vacuum at 200-230° C, a faster process producing greater yields than plant-based alternatives (Camin et al., 2010). Sealed and protected from oxygen and light, squalene has an approximately two-year shelf life, making stable rates of ongoing production important to availability (Camin et al., 2010). Plant-derived squalene can also be refined to a high level of purity for medical applications, and is made up of C₃₀H₅₀ molecules chemically identical to those from shark-derived sources. Plant-derived squalene has been shown to perform comparably to shark-derived squalene as an ingredient in vaccine adjuvants (Brito et al. 2011). Accordingly, the FDA is agnostic on the source of squalene and the *Current Good Manufacturing Practice for Finished Pharmaceuticals* only requires that lots of C₃₀H₅₀ be “tested for conformity with all appropriate written specifications for purity, strength, and quality” (2019). Chemical vendors listed on the NIH National Library of Medicine for squalene do not differentiate by squalene origin but instead identify the compound by Chemical Abstract Services (CAS) number 7683-64-9, meaning there are no legal or administrative barriers preventing a shift to plant-derived sources of squalene (National Center for Biotechnology Information, 2020).

Shark-derived squalene is a popular ingredient in topical cosmetic formulas and lotions, generating a significant portion of global demand for shark liver oil (Lozano-Grande et al., 2018; Ducos et al., 2015). In recent years, however, consumers and non-profit organizations in the United States and Europe have exerted pressure on the cosmetics industry to transition to plant-derived squalene (Consumers unaware of... 2013; Shark Free). Independent testing by the French non-profit organization Bloom determined most beauty products (>90% of those tested) sold in Europe or the United States no longer contain shark-derived ingredients, although shark-derived squalene remains in common use in beauty products elsewhere (Ducos et al., 2015). More recent studies have demonstrated the presence of shark DNA, including from Threatened and Endangered species, in some US-sold beauty products as well (Cardeñosa et al., 2017; Cardeñosa, 2019).

1.1 Squalene in vaccines

Squalene is used as an adjuvant, a component of a vaccine that enhances efficacy by increasing human immune response and the potency of antigens, while promoting antigen transport into lymph nodes and uptake in the immune cells (Brito and O’Hagan, 2014). The inclusion of adjuvants also reduces the volume of antigen needed per vaccine dose through the process of “antigen sparing,” maximizing rates of vaccine production (Tang et al.. 2015; Schmidt et al. 2016). Although the primary global demand for shark liver oil in recent years appears to be for use in cosmetics and lotions (Vannuccini 1999; Lozano-Grande et al., 2018), the role of shark-derived squalene in vaccine production may represent a potential threat to some vulnerable shark populations, given widespread efforts to rapidly develop and disseminate vaccines in response to

the COVID-19 pandemic and the patchwork management approach to global shark fishing limits (Ahn et al., 2020; Hodgson, 2020; Davidson et al. 2016).

As an ingredient in adjuvants, squalene has been found to be safe and effective in vaccines for the treatment of viruses including H7N9 and H7N7 (Wu et al., 2014), H1N1 (Vesikari et al., 2012), MERS-CoV (Zhang et al. 2016), and SARS-CoV (Stadler et al., 2005). MF59, an adjuvant containing shark-derived squalene, has been used commercially in influenza vaccines (Schultze et al. 2008; Panatto et al. 2020) and used or tested in previous vaccines for other coronaviruses (Stadler et al., 2005; Zhang et al., 2016).

A few of the potential SARS-CoV-2 vaccines currently in testing include adjuvants MF59 or AS03, which are known to contain shark-derived squalene (COVID-19 Update 2020; GlaxoSmithKline aims... 2020, WHO, 2020). Per dose, MF59 contains 9.75 mg and AS03 contains 10.68 mg of squalene (Jackson et al., 2015). Some potential vaccines are being manufactured in bulk before the completion of large-scale safety and efficacy trials (U.S. to Stockpile... 2020), suggesting that the total number of manufactured doses of various potential vaccines may be far higher than the number ultimately administered. It also remains unknown how frequently revaccination would be necessary if a safe and effective vaccine becomes available (COVID-19 Could Become... 2020; Ellis, 2020; Vaccine companies... 2020), so the scale of possible future demand for squalene as an ingredient in vaccine adjuvants is large but difficult to fully or accurately assess.

Deep-sea sharks are valued in the shark liver oil trade because they offer greater volumes of liver oil than other species. Relatively little is known about population structure, reproduction, and habitat use of many of these species due to the logistical difficulties of conducting research in deep-sea habitats and a generally low research and management priority (e.g., Neiva et al., 2006; Kyne and Simpfendorfer, 2007; Veríssimo et al., 2011). Most elasmobranchs are slow to mature and reproduce, and deep-sea sharks are particularly so, showing population increase rates of less than half those of continental shelf and pelagic shark species relying on shallower habitats (Simpfendorfer and Kyne, 2009). Squaloid sharks (species found in order squaliformes) are a preferred source of liver oil and squalene, and include species which are among the slowest growing and latest maturing sharks known (Musick, 2005). Shark reproductive rates and recovery potential generally decline with increasing depth, and overfished populations of deep-sea shark species may require centuries to recover (Simpfendorfer and Kyne, 2009). Evidence suggests that even low rates of deep-sea shark exploitation (incidental or targeted) is likely to quickly deplete populations (Simpfendorfer and Kyne, 2009). For these reasons, deep-sea sharks have been identified as a conservation priority grouping (Dulvy et al., 2014).

Assessment of the global conservation status of sharks is complicated by poor catch reporting, challenges with species-level identification, and a lack of baseline data. The reported annual catch of sharks likely substantially underestimates actual total catch (Worm et al., 2013; Dulvy et al., 2014). Total catch has been estimated at approximately 100 million animals annually, with an estimate range of 63 to 273 million (Worm et al., 2013). It is particularly difficult to assess rates of capture for species targeted for products like shark liver oil, for which there is relatively little detailed production or trade information available (Fowler et al., 1997; Vannuccini, 1999).

The global trade in shark liver oil is small compared to that in shark fins or meat, and despite the vulnerability of some target species to overfishing has received relatively little media (Shiffman et al., 2020) or scientific attention (Dent and Clarke, 2015). Although there are fisheries in which deep-sea sharks are targeted (see, e.g., Simpfendorfer and Kyne, 2007), liver oil may also be generated opportunistically from incidental catches in fisheries predominantly targeting other fish, or targeting sharks for other products (e.g., meat, fins). In at least some cases, however, the export value of shark liver oil exceeds that of shark meat, and in some locales the available supply of shark liver oil is insufficient to meet processors' demand for raw materials (Dent and Clarke, 2015). A lack of traceability presents a further challenge in assessing the trade in shark liver oil, as the United Nations Food and Agriculture Organization (FAO)'s *Codex Alimentarius* allows for products like squalene to be labelled as originating in the countries in which they were processed even when ingredients (e.g., the liver oil from which the squalene was derived) were produced elsewhere (FAO, 2001).

This study provides a basis for beginning to evaluate the range of potential conservation effects of increasing demand for shark-derived squalene as an ingredient in vaccine adjuvants.

2. Materials and methods

Based on a review of available scientific and management literature, 133 species were identified which are known to be involved in the liver oil trade (Appendix 1), including many that are partially reliant on deep-sea habitat >200 m (n=83) or are found exclusively in the deep-sea (n=21). Additional data on the conservation status and population trends of elasmobranch species, primarily sharks, identified as being involved in the liver oil trade were compiled from their most recent IUCN Red List assessments. Available current trade data on the shark liver oil trade was downloaded from the UN FAO FishStat Database (FAO, 2020). Commercial sources of wholesale quantities of squalene were identified through internet searches and through direct contact with wholesalers to collect pricing, origin, and availability information for both plant- and shark-derived squalene and squalane (its more stable, hydrogenated derivate).

3. Results

Across elasmobranch species identified as being exploited for shark liver oil, 50% had not been assessed by the IUCN in at least ten years, and 30% were considered Data Deficient (Figure 1; an IUCN Shark Specialist Group reassessment of elasmobranch species is currently underway and expected to be completed in 2020 (Dulvy, 2018)). One-third of species identified as part of the shark liver oil trade are classified as threatened (Vulnerable, Endangered, or Critically Endangered) according to IUCN Red List criteria (Figure 2). Population trends for 56% of these species are unknown, and 34% are assessed as showing a decreasing trend (Figure 3).

The most recent FAO data available (2018) showed an increase in reported import and processed production of shark liver oil, with trade volumes reaching 752 tons, the largest reported volume in decades (Figure 4; from 2000-2017, average reported trade volume was under 200 tons annually; Hareide et al., 2007). Despite this increase, the total value of the shark liver oil trade was reported at 553 000 USD in 2018, the lowest value reported since 1987 (mean annual value from 2000-2017, 1 954 000 USD; Hareide et al. 2007; FAO, 2020). Moderate assumptions about

oil yield suggest the range of individual animals in the reported global liver oil trade in 2018 falls between 694 848 (large sharks) and 16.35 million (small sharks), with 1.8 million (based on a 20.8 kg median unidentified shark weight; Worm et al. 2013) as the best supported rough estimate (for yield assumptions see Table 1).

Data collected on the price of shark- and plant-derived squalene showed no clear differences, though products listed as both shark- and plant-derived were commonly available in the wholesale market (Table 2). There was significant variability in price across individual sellers (ranging from \$20-260/kg for squalene and \$10-99.21/kg for squalane). The mean and median price for plant-derived squalene was \$40, and the mean price for shark-derived squalene was \$45.75 with a median of \$48.5/kg (excluding the outlier of \$260; including it, the mean price for shark-derived squalene was \$76.36, with a median price of \$54). The mean price for plant-derived squalane was \$53.16/kg (median \$48.65/kg), while shark-derived squalane was \$45/kg (median \$45/kg). These products were identified as being sold from China (67% of products) and the United States (33% of products). Based on these numbers, the estimated potential commercial value of squalene from a single shark ranges from \$0.05 (small shark/low yield) to \$242.65 (large shark/high yield).

Given that each vaccine dose requires approximately 10mg of squalene, the mean squalene cost-per-vaccine-dose for shark-derived squalene would be \$0.0004575 USD, and for plant-derived, \$0.0004 USD—a price difference of \$0.0000575 per dose.

4. Discussion

These results highlight the extent to which liver oil fisheries could affect shark species of conservation concern, and the potential difficulty of detecting these effects because of a lack of information on the volume of liver-oil-associated catch and the absence of population status information for many deep-sea species. The life history characteristics of deep-sea sharks (Simpfendorfer and Kyne, 2009), insufficient restrictions on exploitation, and declines in availability of shark-derived squalene over time (Sibuyo et al., 2017) suggest that the trade in shark liver oil, while currently small, has potential to disproportionately harm specific vulnerable elasmobranch species and populations.

Estimating potential conservation effects is further complicated by the fact that shark species vary greatly in the percentage of their body weight comprised of the liver (from at least 2.9-20%; Vannucini, 1999; Abel and Grubbs, 2020); in the amount of liver weight made up of oil (ranging from at least 10-70%; Nichols et al., 2001); and in the yield of squalene from extracted liver oil (a range of at least 15-82%; Deprez et al., 1990; Bakes & Nichols 1995). Evidence further suggests animal size, sex, and seasonal and regional factors can also affect yields (Kreuzer and Ahmed, 1978; Nichols et al., 2001). Accordingly, it is impossible to calculate an exact effect of increased vaccine-related demand for shark-derived squalene on shark populations.

We know that fisheries primarily targeting sharks for liver oil exist (e.g., Kyne and Simpfendorfer, 2007), and that, in many cases, multiple products may be marketed from a single shark (e.g., meat, fins, liver oil, cartilage). Data are not available to assess the volume of liver oil generated globally by directed versus incidental fishing. The effect of increased demand for

shark-derived squalene is highly dependent on whether it increases targeting of oil-rich deep-sea sharks, or simply drives increased processing and use of the livers of sharks currently taken for other purposes. Thus, conservation effects of vaccine-related demand for squalene could range from minimal (assuming demand is met by more efficient use of individuals already being landed in well-managed fisheries) to catastrophic for individual species (if demand drives the creation of new targeted fisheries for vulnerable deep-sea species in the absence of limits on fishing and trade).

The future availability of shark squalene will likely be constrained by shark population declines and by regulatory efforts to conserve sharks, suggesting the prudence of shifting to more stable and sustainable sources. A vaccine supply chain dependent on shark fisheries is subject to disruption if targeted shark populations collapse or new protections are introduced. Plant-derived alternatives to shark-derived squalene are more environmentally sustainable and readily available. Although in the past shark-derived squalene was reported to be significantly less expensive than plant-derived (Camin et al., 2010), current costs are similar. Non-animal-derived squalene may even be safer for use in some health-related applications because of the reduced risk of contamination with persistent organic pollutants, including polychlorinated biphenyls and organochlorine insecticides, high levels of which have been found in nutritional supplements made from shark liver oil (Rawn et al., 2009).

Despite generally comparable costs between shark- and plant-derived squalene, and potential advantages in long-term availability and contaminant levels, non-animal-derived squalene does not appear to be in current use in vaccine production. Consumer and activist pressure could be effective in encouraging pharmaceutical companies to transition to non-animal-derived squalene in adjuvants, for testing for other medical uses, and in nutraceutical products. Demand-driven increases in production of pharmaceutical grade plant-derived alternatives may also incidentally support reduction or elimination of shark-derived squalene in cosmetic formulations. Increased accountability, including product testing to confirm plant origins and transparency within supply chains, would be vital to a transition away from reliance on shark-derived squalene.

5. Conclusion

The mean difference in cost per dose of a potential SARS-CoV-2 vaccine containing squalene derived from plants instead of shark liver oil is -\$0.0000575, based on currently available wholesale price information. While commercially available wholesale squalene may not meet the standard of purity needed for pharmaceutical applications, given these values it would cost \$20,125.00 less to generate the 350 million doses needed to vaccinate the U.S. population with plant- rather than shark-derived squalene. Doing the same for the global population of 7 billion would save \$402,500.00 over use of shark-derived squalene (without accounting for the effects high demand might have on price or availability).

In addition to similarities in cost, plant-derived sources of squalene have been shown to work comparably as an ingredient in adjuvants, and should not require a new approval process for use because they are chemically identical. Therefore, a shift to non-animal-derived squalene is highly feasible without disrupting efforts to rapidly develop a vaccine. A coordinated commitment by

the medical sector to transition to non-animal-derived squalene would support both environmental sustainability and public health goals.

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Works Cited

- Abel D.C., Grubbs R.D., 2020. Shark Biology and Conservation: Essentials for Educators, Students, and Enthusiasts. John Hopkins University Press, Baltimore, MD.
- Ahn D-G, Shin H-J, Kim M-H, Lee S, Kim H-S, Myoung J, Kim B-T, Kim S-J., 2020. Current Status of Epidemiology, Diagnosis, Therapeutics, and Vaccines for Novel Coronavirus Disease 2019 (COVID-19). Journal of Microbiology and Biotechnology. 30(3), 313–324. doi:10.4014/jmb.2003.03011.
- Ali K., Sinan H., 2014. Shark ban in its infancy: Successes, challenges and lessons learned. Ali, K., & Sinan, H. (2014). Shark ban in its infancy: Successes, Challenges and Lessons Learned. Journal of the Marine Biological Association of India. 56(1), 34–40. doi:10.6024/jmbai.2014.56.1.01750s-05.
- Anderson, R.C., Waheed, Z., 1999. Management of shark fisheries in the Maldives, in Shotton, R. (Ed.), Case studies of the management of elasmobranch fisheries. [accessed 2020 Sep 10]. <http://www.fao.org/3/X2097E/X2097E17.htm>.
- Bakes M.J., Nichols P.D., 1995. Lipid, fatty acid and squalene composition of liver oil from six species of deep-sea sharks collected in southern Australian waters. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology. 110(1), 267-75.
- Brito L.A., Chan M., Baudner B., Gallorini S., Santos G., O’Hagan D.T., Singh M., 2011. An alternative renewable source of squalene for use in emulsion adjuvants. Vaccine. 29(37), 6262–6268. doi:<http://dx.doi.org.colorado.idm.oclc.org/10.1016/j.vaccine.2011.06.067>.
- Brito L.A., O’Hagan D.T., 2014. Designing and building the next generation of improved vaccine adjuvants. Journal of Controlled Release. 190, 563–579. doi:10.1016/j.jconrel.2014.06.027.
- Camin F., Bontempo L., Ziller L., Piangiolino C., Morchio G., 2010. Stable isotope ratios of carbon and hydrogen to distinguish olive oil from shark squalene-squalane: Distinguishing olive oil from shark squalene-squalane. Rapid communications in mass spectrometry. 24(12), 1810–1816. doi:10.1002/rcm.4581.
- Cardenosa D. 2019. Genetic identification of threatened shark species in pet food and beauty care products. Conservation Genetics. 20(6), 1383–1387. doi:10.1007/s10592-019-01221-0.
- Cardenosa D., Fields A., Abercrombie D., Feldheim K., Shea S.K.H., Chapman D.D. 2017. A multiplex PCR mini-barcode assay to identify processed shark products in the global trade. PLoS ONE. 12(10), e0185368. doi:10.1371/journal.pone.0185368.
- Current Good Manufacturing Practice for Finished Pharmaceuticals*, 21 C.F.R. § 211.84 (2019).

325 Ducos, L., Guillonneau, V., Le Manach, F., Nouvian C. (2015). Beauty and the beast: Shark in
326 our beauty creams. [http://www.bloomassociation.org/en/wp-content/uploads/2018/04/squalane-](http://www.bloomassociation.org/en/wp-content/uploads/2018/04/squalane-bloom-english-1.pdf)
327 [bloom-english-1.pdf](http://www.bloomassociation.org/en/wp-content/uploads/2018/04/squalane-bloom-english-1.pdf) (accessed 22 Jun 2020).

328 Consumers unaware of..., 2013. Consumers unaware of endangered shark liver oil in cosmetics.
329 Oceana EU. [https://eu.oceana.org/en/press-center/press-releases/consumers-unaware-](https://eu.oceana.org/en/press-center/press-releases/consumers-unaware-endangered-shark-liver-oil-cosmetics)
330 [endangered-shark-liver-oil-cosmetics](https://eu.oceana.org/en/press-center/press-releases/consumers-unaware-endangered-shark-liver-oil-cosmetics) (accessed 28 Aug 2020).

331 COVID-19 Could Become..., 2020. COVID-19 Could Become a Seasonal Illness: What We'll
332 Need to Do. Healthline. [https://www.healthline.com/health-news/covid19-could-become-](https://www.healthline.com/health-news/covid19-could-become-seasonal-just-like-the-flu)
333 [seasonal-just-like-the-flu](https://www.healthline.com/health-news/covid19-could-become-seasonal-just-like-the-flu) (accessed 5 Aug 2020).

334 COVID-19 Update, 2020. COVID-19 Update. <https://www.seqirus.com/news/covid19-update>
335 [access 4 Aug 2020](https://www.seqirus.com/news/covid19-update)).

336 Davidson, L. N., Krawchuk, M. A., Dulvy, N. K., 2016. Why have global shark and ray landings
337 declined: improved management or overfishing?. *Fish and Fisheries*. 17(2), 438-458.
338

339 Dent F., Clarke S., 2015. State of the global market for shark products. *FAO Fisheries and*
340 *Aquaculture Technical Paper*, 590.

341 Deprez P.P., Volkman J.K., Davenport S.R., 1990. Squalene content and neutral lipids
342 composition of Livers from Deep-sea sharks caught in Tasmanian waters. *Marine and*
343 *Freshwater Research*. 41(3), 375-87.

344 Dulvy N.K., Fowler S.L., Musick J.A., Cavanagh R.D., Kyne P.M., Harrison L.R., Carlson J.K.,
345 Davidson L.N., Fordham S.V., Francis M.P., et al., 2014. Extinction risk and conservation of the
346 world's sharks and rays. *eLife*. 3:e00590. doi:10.7554/eLife.00590.

347 Dulvy, N.K., 2018. The Global Shark Trends Project: A New Era for the IUCN SSC Shark
348 Specialist Group. [https://www.iucnssg.org/a-new-era-for-the-iucn-ssc-shark-specialist-](https://www.iucnssg.org/a-new-era-for-the-iucn-ssc-shark-specialist-group.html)
349 [group.html](https://www.iucnssg.org/a-new-era-for-the-iucn-ssc-shark-specialist-group.html) (accessed 5 October 2020).
350

351 Ellis R., 2020. COVID-19 Vaccine Will Probably Require Two Doses.
352 [https://www.webmd.com/lung/news/20200605/covid-19-vaccine-will-probably-require-two-](https://www.webmd.com/lung/news/20200605/covid-19-vaccine-will-probably-require-two-doses)
353 [doses](https://www.webmd.com/lung/news/20200605/covid-19-vaccine-will-probably-require-two-doses) (accessed 5 Aug 2020).

354 Food & Agricultural Organization (FAO), 2001. Codex general standard for the labelling of
355 prepackaged foods. <http://www.fao.org/3/Y2770E/y2770e02.htm> (accessed 11 Sep 2020).

356 [dataset] FAO, 2020. FishStatJ—software for fishery statistical time
357 series. <http://www.fao.org/fishery/statistics/software/fishstatj/en> (accessed 4 Oct 2020).
358

359 Fowler E.S.L., Reed T.M., Dipper F.A., 1997. Elasmobranch Biodiversity, Conservation and
360 Management: Proceedings of the International Seminar and Workshop, Sabah, Malaysia, July
361 1997. IUCN SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. xv +
362 258 pp.

363 GlaxoSmithKline aims... 2020. GlaxoSmithKline aims to make 1B doses of vaccine booster for
364 multiple COVID-19 partners. [https://www.fiercepharma.com/manufacturing/glaxosmithkline-](https://www.fiercepharma.com/manufacturing/glaxosmithkline-aims-to-make-1b-doses-vaccine-booster-for-multiple-covid-19-partners)
365 [aims-to-make-1b-doses-vaccine-booster-for-multiple-covid-19-partners](https://www.fiercepharma.com/manufacturing/glaxosmithkline-aims-to-make-1b-doses-vaccine-booster-for-multiple-covid-19-partners) (accessed 4 Aug 2020).

366 Hareide N.R., Carlson J., Clarke M., Clarke S., Ellis J., Fordham S., Pinho M., Fowler S., Serena
367 F., Raymakers C., 2007. European Shark Fisheries: A Preliminary Investigation into Fisheries,
368 Conversion Factors, Trade Products, Markets and Management Measures. European
369 Elasmobranch Association. [accessed 2020 Sep 27].
370 http://sasamaconsulting.com/en/pdf/Hareide_2007.pdf (27 Sep 2020)

371 Hodgson J., 2020. The pandemic pipeline. *Nature Biotechnology*. 38(5), 523–532.
372 doi:10.1038/d41587-020-00005-z.

373 Jackson L.A., Campbell J.D., Frey S.E., Edwards K.M., Keitel W.A., Kotloff K.L., Berry A.A.,
374 Graham I., Atmar R.L., Creech C.B., et al., 2015. Effect of Varying Doses of a Monovalent
375 H7N9 Influenza Vaccine With and Without AS03 and MF59 Adjuvants on Immune Response: A
376 Randomized Clinical Trial. *JAMA*. 314(3), 237–246. doi:10.1001/jama.2015.7916.

377 Kreuzer, R. & Ahmed, R, 1978. Shark utilization and marketing. FAO. Rome.

378
379 Kyne P.M., Simpfendorfer, C.A., 2007. A collation and summarization of available data on
380 deepwater Chondrichthyans: biodiversity, life history and fisheries. A report prepared by the
381 IUCN SSC Shark Specialist Group for the Marine Conservation Biology Institute.
382 https://www.iucnssg.org/uploads/5/4/1/2/54120303/deepwater_chondrichthyans.pdf (accessed 5
383 Oct 2020).

384
385 Kim S-K., Karadeniz F., 2012. Biological Importance and Applications of Squalene and
386 Squalane. in *Advances in Food and Nutrition Research*. Vol. 65. Academic Press.

387 Lack M., Sant G., 2009. Trends in Global Shark Catch and Recent Developments in
388 Management. Traffic International. [https://www.traffic.org/publications/reports/trends-in-global-](https://www.traffic.org/publications/reports/trends-in-global-shark-catch/)
389 [shark-catch/](https://www.traffic.org/publications/reports/trends-in-global-shark-catch/) (accessed 4 Aug 2020).

390 Lozano-Grande M.A., Gorinstein S., Espitia-Rangel E., Dávila-Ortiz G., Martínez-Ayala A.L.,
391 2018. Plant Sources, Extraction Methods, and Uses of Squalene. *International Journal of*
392 *Agronomy*. 1–13. doi:10.1155/2018/1829160.

393 Musick J.A., 2005. Shark Utilization, in Musick, J.A., Bonfil, R. (Eds.), *Management*
394 *Techniques for elasmobranch fisheries*. FAO Fisheries Technical Paper 474, 243- 251.

395 National Center for Biotechnology Information (2020). PubChem Compound Summary for CID
396 638072, Squalene. Retrieved October 13, 2020 from
397 <https://pubchem.ncbi.nlm.nih.gov/compound/Squalene>.

398
399 Neiva, J., Coelho, R., & Erzini, K. 2006. Feeding habits of the velvet belly lanternshark
400 *Etmopterus spinax* (Chondrichthyes: Etmopteridae) off the Algarve, southern Portugal. *Marine*
401 *Biological Association of the United Kingdom. Journal of the Marine Biological Association of*
402 *the United Kingdom*. 86(4), 835.

- 403 Nichols P., Rayner M., Stevens J.D., 2001. A pilot investigation of Northern Australian shark
404 liver oils: characterization and value-adding. CSIRO Marine Research. FRDC Project 99/369.
405 <http://frdc.com.au/Archived-Reports/FRDC%20Projects/1999-369-DLD.pdf> (accessed 5 Oct
406 2020).
- 407
- 408 Panatto D., Haag M., Lai P.L., Tomczyk S., Amicizia D., Lino M.M., 2020. Enhanced Passive
409 Safety Surveillance (EPSS) confirms an optimal safety profile of the use of MF59®-adjuvanted
410 influenza vaccine in older adults: Results from three consecutive seasons. *Influenza Other
411 Respiratory Viruses*. 14(1), 61–66. doi:10.1111/irv.12685.
- 412 Rawn D.F.K., Krakalovich T., Forsyth D.S., Roscoe V., 2009. Analysis of fin and non-fin fish
413 products for azamethiphos and dichlorvos residues from the Canadian retail market. *International
414 Journal of Food Science & Technology*. 44(8), 1510–1516. doi:10.1111/j.1365-
415 2621.2007.01678.x.
- 416 Schmidt R., Holznagel E., Neumann B., Alex N., Sawatsky B., Enkirch T., Pfeffermann K.,
417 Kruip C., von Messling V., Wagner R., 2016. Squalene-containing licensed adjuvants enhance
418 strain-specific antibody responses against the influenza hemagglutinin and induce subtype-
419 specific antibodies against the neuraminidase. *Vaccine*. 34(44), 5329–5335.
420 doi:10.1016/j.vaccine.2016.08.082.
- 421 Schultze V., D’Agosto V., Wack A., Novicki D., Zorn J., Hennig R., 2008. Safety of MF59(TM)
422 adjuvant. *Vaccine*. 26(26), 3209–3222.
423 doi:<http://dx.doi.org.colorado.idm.oclc.org/10.1016/j.vaccine.2008.03.093>.
- 424 Shark Free. Shark Free - Shark Angels. Shark Angels. [https://sharkangels.org/what-we-do/shark-](https://sharkangels.org/what-we-do/shark-free)
425 [free](https://sharkangels.org/what-we-do/shark-free) (accessed 28 Aug 2020).
- 426 Shiffman D.S., Bittick S.J., Cashion M.S., Colla S.R., Cristine L.E., Derrick D.H., Gow E.A.,
427 Macdonald C.C., More O’Ferrall M., Orobko M., et al., 2020. Inaccurate and Biased Global
428 Media Coverage Underlies Public Misunderstanding of Shark Conservation Threats and
429 Solutions. *iScience*. 23(6), 101205. doi:10.1016/j.isci.2020.101205.
- 430 Sibuyo L., Widiputri D., Legowo E., 2017. Optimization of squalene extraction from Palm Fatty
431 Acid Distillate (PFAD) in multistage process. *AIP Conference Proceedings*. 1803(1), 020060.
432 doi:10.1063/1.4973187.
- 433 Simpfendorfer C.A., Kyne P.M., 2009. Limited potential to recover from overfishing raises
434 concerns for deep-sea sharks, rays and chimaeras. *Environmental Conservation*. 36(2), 97–103.
435 doi:10.1017/S0376892909990191.
- 436 Stadler K., Roberts A., Becker S., Vogel L., Eickmann M., Kolesnikova L., Klenk H-D., Murphy
437 B., Rappuoli R., Abrignani S., et al., 2005. SARS Vaccine Protective in Mice. *Emerging
438 Infectious Diseases*. 11(8), 1312–1314. doi:10.3201/eid1108.041003.
- 439 Stevens J., Bonfil R., Dulvy N., Walker P., 2000. The effects of fishing on sharks, rays, and
440 chimaeras (Chondrichthyans), and the implications for marine ecosystems. *ICES Journal of
441 Marine Science*. 57, 476–494. doi:10.1006/jmsc.2000.0724.

442 Tang J., Zhang N., Tao X., Zhao G., Guo Y., Tseng C-TK., Jiang S., Du L., Zhou Y., 2015.
 443 Optimization of antigen dose for a receptor-binding domain-based subunit vaccine against
 444 MERS coronavirus. *Human vaccines & immunotherapeutics*. 11(5), 1244–1250.
 445 doi:10.1080/21645515.2015.1021527.

446 U.S. to Stockpile... 2020. U.S. to stockpile vaccine candidates as trials continue: health secretary.
 447 Reuters. <https://www.reuters.com/article/us-health-coronavirus-usa-vaccine-idUSKBN22R2C0>
 448 (accessed 5 Aug 2020).

449 Vaccine companies... 2020. Vaccine companies searching for 1-shot dose of COVID-19 vaccine.
 450 ABC News. [https://abcnews.go.com/Health/vaccine-companies-searching-shot-dose-covid-19-](https://abcnews.go.com/Health/vaccine-companies-searching-shot-dose-covid-19-vaccine/story?id=72053977)
 451 [vaccine/story?id=72053977](https://abcnews.go.com/Health/vaccine-companies-searching-shot-dose-covid-19-vaccine/story?id=72053977) (accessed 5 Aug 2020).

452 Vannuccini S. 1999. Shark utilization, marketing and trade (No. 389). FAO FISHERIES
 453 TECHNICAL PAPER, 389. <http://www.fao.org/3/x3690e/x3690e1d.htm> (accessed 29 Jun
 454 2020).

455 Veríssimo D., MacMillan D.C., Smith R.J., 2011. Toward a systematic approach for identifying
 456 conservation flagships: Identifying conservation flagships. *Conservation Letters*. 4(1), 1–8.
 457 doi:10.1111/j.1755-263X.2010.00151.x.

458 Vesikari T., Pepin S., Kusters I., Hoffenbach A., Denis M., 2012. Assessment of squalene
 459 adjuvanted and non-adjuvanted vaccines against pandemic H1N1 influenza in children 6 months
 460 to 17 years of age. *Human vaccines & immunotherapeutics*. 8(9), 1283–1292.
 461 doi:10.4161/hv.21265.

462 World Health Organization (WHO), 2020. Draft landscape of COVID-19 candidate vaccines.
 463 <https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines>
 464 (accessed 5 Oct 2020).

465 Worm B., Davis B., Kettemer L., Ward-Paige C.A., Chapman D., Heithaus M.R., Kessel S.T.,
 466 Gruber S.H., 2013. Global catches, exploitation rates, and rebuilding options for sharks. *Marine*
 467 *Policy*. 40, 194–204. doi:10.1016/j.marpol.2012.12.034.

468 Wu C-Y., Chang C-Y., Ma H-H., Wang C-W., Chen Y-T., Hsiao P-W., Chang C-C., Chan C-H.,
 469 Liu C-C., Chen J-R., 2014. Squalene-adjuvanted H7N9 virus vaccine induces robust humoral
 470 immune response against H7N9 and H7N7 viruses. *Vaccine*. 32(35), 4485–4494.
 471 doi:10.1016/j.vaccine.2014.06.043.

472 Zhang N., Channappanavar R., Ma C., Wang L., Tang J., Garron T., Tao X., Tasneem S., Lu L.,
 473 Tseng C-TK., et al., 2016. Identification of an ideal adjuvant for receptor-binding domain-based
 474 subunit vaccines against Middle East respiratory syndrome coronavirus. *Cellular & molecular*
 475 *immunology*. 13(2), 180–190. doi:10.1038/cmi.2015.03.

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Table 1

Estimated number of sharks needed to produce two vaccine doses for the global human population under a range of yield assumptions.

Shark weight (kg)	Liver weight	Liver oil weight	Squalene weight	Total sharks*
	Best case			
	<u>20%</u>	<u>70%</u>	<u>82%</u>	
2.3 kg (small shark)	0.46	0.32	0.26	576,049
5.6 kg (deep-sea shark)	1.12	0.78	0.64	236,592
20.8 kg shark (median)	4.16	2.91	2.39	63, 693
46.2 kg (large shark)	9.24	6.47	5.30	28,678
	Moderate case			
	<u>10%</u>	<u>40%</u>	<u>50%</u>	
2.3 kg (small shark)	0.23	0.09	0.05	3,306,522
20.8 kg shark (median)	2.08	0.83	0.42	365,385
46.2 kg (large shark)	4.62	1.85	0.92	164,610
	Worst case			
	<u>3%</u>	<u>10%</u>	<u>15%</u>	
2.3 kg (small shark)	0.069	0.007	0.00104	146,956,522
20.8 kg shark (median)	0.624	0.062	0.00936	16,239,316
46.2 kg (large shark)	1.386	0.139	0.02079	7,316,017

* Based on a maximum demand estimate, assuming use of MF59 adjuvant containing 9.75 mg of squalene per dose to provide 2 vaccines to 7.8 billion people, total squalene demand for vaccines (drawn from existing or new fisheries) would be 152,100 kg.

Table 2

Current listed wholesale prices of shark- and plant-derived squalene and squalane by kg in USD.

Squalene			
<u>Source</u>	<u>Price/Kg (USD)</u>	<u>Sold From</u>	<u>Manufacturer</u>
Shark	\$39-47	China	Xi'an Rozen Biotechnology Co., Ltd
Shark	\$25	China	Xa Bc-Biotech Co., Ltd
Shark	\$54	China	Wuhan Hengheda Pharm Co., Ltd
Shark	\$260	China	Haihang Industry Co., Ltd
Shark	\$35-80	China	Xi'an Sheerherb Biological Technology
Shark	\$20-60	China	Shandong Zesheng Chemical Co., Ltd
Shark	\$55	China	Shaanxi Phoenix Tree Biotech Co., Ltd
Olive Oil	\$20-60	China	Suzhou Manson Biotech Co., Ltd
Soybeans	\$20-60	China	Suzhou Manson Biotech Co., Ltd
Squalane			
<u>Source</u>	<u>Price/Kg (USD)</u>	<u>Sold From</u>	<u>Manufacturer</u>
Shark	~\$40	USA	Jedwards International INC.
Shark	\$50	China	Xa Bc-Biotech Co, Ltd
Olive Oil	\$44.89	USA	Cocojojo Beauty
Olive Oil	\$63.99	USA	Organic Gold
Olive Oil	\$10-20	China	Shandong Zhonglan Chemical Co., Ltd
Olive Oil	\$40-60	China	Xi'an Geekee Biotech Co., Ltd
Olive Oil	~\$51.75	USA	Jedwards International INC.
Olive Oil	~\$47.30	USA (Origin Italy, Spain)	Blossom Bulk Ingredients
Neossance (Sugarcane)	\$99.21	USA	HBNO

Figure 1. Most recent IUCN Red List assessments for assessed elasmobranch species (n=131) reported in the liver oil trade. The earliest assessment of a species identified as traded for liver oil took place in 2003.

Figure 2. IUCN Red List conservation status of elasmobranch species reported in the liver oil trade.

Population Trends of Elasmobranch Species Used
in the Squalene and Liver Oil Industries

Figure 3. IUCN Red List population trends of all elasmobranch species reported in the liver oil trade.

Total Net Weight (tonnes) per year of shark liver oil trade
reported to FAO

Figure 4. The total reported net weight (tonnes) of annual trade in shark liver oil reported to FAO. In 2018, two countries reported trade: imports of 33 tonnes (Republic of Korea) and processed production of 719 tonnes (Senegal).

Appendix A: Elasmobranchs reported to be used in the liver oil and squalene trades, including IUCN conservation status and population trend assessment information.

Table A.1

Scientific Name	Family Name	Common Name	Source	IUCN Conservation Status	IUCN Assessed Population Trend	Year Last Assessed
<i>Alopias pelagicus</i>	Alopiidae	Pelagic Thresher	Vannuccini 1999	EN	Decreasing	2018
<i>Alopias superciliosus</i>	Alopiidae	Bigeye Thresher	Vannuccini 1999	VU	Decreasing	2018
<i>Alopias vulpinas</i>	Alopiidae	Common Thresher	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2018
<i>Anoxypristis cuspidata</i>	Pristidae	Knifetooth Sawfish/Narrow Sawfish	Fowler et al., 1997	EN	Decreasing	2012
<i>Atelomycterus baliensis</i>	Scyliorhinidae	Bali Catshark	Fowler et al., 1997	VU	Unknown	2008
<i>Atelomycterus fasciatus</i>	Scyliorhinidae	Banded Catshark	Fowler et al., 1997	LC	Unknown	2015
<i>Atelomycterus macleayi</i>	Scyliorhinidae	Australian Marbled Catshark	Fowler et al., 1997	LC	Unknown	2015
<i>Atelomycterus marmoratus</i>	Scyliorhinidae	Coral Catshark	Fowler et al., 1997	NT	Unknown	2003
<i>Atelomycterus marnkalha</i>	Scyliorhinidae	Eastern Banded Catshark	Fowler et al., 1997	DD	Unknown	2015
<i>Aulohaelurus kanakorum</i>	Scyliorhinidae	New Caledonia Catshark	Fowler et al., 1997	DD	Unknown	2017
<i>Aulohaelurus labiosus</i>	Scyliorhinidae	Black Spotted Catshark	Fowler et al., 1997	LC	Unknown	2015
<i>Carcharhinus albimarginatus</i>	Carcharhinidae	Silvertip Shark	Vannuccini 1999	VU	Decreasing	2015
<i>Carcharhinus altimus</i>	Carcharhinidae	Bignose Shark	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2008
<i>Carcharhinus amblyrhynchos</i>	Carcharhinidae	Grey Reef Shark	Vannuccini 1999	NT	Unknown	2005
<i>Carcharhinus brevipinna</i>	Carcharhinidae	Spinner Shark	Fowler et al., 1997;	NT	Unknown	2005

			Vannuccini 1999			
<i>Carcharhinus falciformis</i>	Carcharhinidae	Silky Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2017
<i>Carcharhinus leucas</i>	Carcharhinidae	Bull Shark	Fowler et al., 1997; Vannuccini 1999	NT	Unknown	2005
<i>Carcharhinus limbatus</i>	Carcharhinidae	Blacktip Shark	Fowler et al., 1997; Vannuccini 1999	NT	Unknown	2005
<i>Carcharhinus longimanus</i>	Carcharhinidae	Oceanic Whitetip Shark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2018
<i>Carcharhinus melanopterus</i>	Carcharhinidae	Blacktip Reef Shark	Fowler et al., 1997; Vannuccini 1999	NT	Decreasing	2005
<i>Carcharhinus obscurus</i>	Carcharhinidae	Dusky Shark	Fowler et al., 1997; Vannuccini 1999	EN	Decreasing	2018
<i>Carcharhinus plumbeus</i>	Carcharhinidae	Sandbar Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2007
<i>Carcharias taurus</i>	Odontaspidae	Sand Tiger Shark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2016
<i>Carcharodon carcharias</i>	Lamnidae	White Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2018
<i>Centrophorus acus</i>	Centrophoridae	Needle Dogfish	Fowler et al., 1997; Vannuccini 1999	Not Listed	Not Listed	Not Listed
<i>Centrophorus lusitanicus</i>	Centrophoridae	Lowfin Gulper Shark	Fowler et al., 1997; Vannuccini 1999	VU	Unknown	2008
<i>Centrophorus niaukang</i>	Centrophoridae	Taiwan Gulper Shark	Fowler et al., 1997	Not Listed	Not Listed	Not Listed

<i>Centrophorus squamosus</i>	Centrophoridae	Leafscale Gulper Shark	Fowler et al., 1997;; Vannuccini 1999	VU	Decreasing	2003
<i>Centroselachus crepidater</i>	Somniosidae	Longnose Velvet Dogfish	Fowler et al., 1997; Vannuccini 1999	LC	Unknown	2003
<i>Cephaloscyllium albipinnum</i>	Scyliorhinidae	Whitefin Swellshark	Fowler et al., 1997	CR	Decreasing	2018
<i>Cephaloscyllium cooki</i>	Scyliorhinidae	Cook's Swellshark	Fowler et al., 1997	DD	Unknown	2015
<i>Cephaloscyllium fasciatum</i>	Scyliorhinidae	Reticulated Swellshark	Fowler et al., 1997	DD	Unknown	2010
<i>Cephaloscyllium hiscosellum</i>	Scyliorhinidae	Reticulate Swellshark	Fowler et al., 1997	LC	Unknown	2015
<i>Cephaloscyllium isabellum</i>	Scyliorhinidae	Carpet Shark	Fowler et al., 1997	LC	Stable	2017
<i>Cephaloscyllium laticeps</i>	Scyliorhinidae	Australian Swellshark	Fowler et al., 1997	LC	Stable	2015
<i>Cephaloscyllium maculatum</i>	Scyliorhinidae	Spotted Swellshark	Fowler et al., 1997	DD	Unknown	2010
<i>Cephaloscyllium pardelotum</i>	Scyliorhinidae	Leopard-spotted Swellshark	Fowler et al., 1997	DD	Unknown	2010
<i>Cephaloscyllium sarawakensis</i>	Scyliorhinidae	Sarawak Pygmy Swell Shark	Fowler et al., 1997	DD	Unknown	2008
<i>Cephaloscyllium signourum</i>	Scyliorhinidae	Flagtail Swellshark	Fowler et al., 1997	DD	Unknown	2015
<i>Cephaloscyllium silasi</i>	Scyliorhinidae	Indian Swellshark	Fowler et al., 1997	DD	Unknown	2008
<i>Cephaloscyllium speccum</i>	Scyliorhinidae	Speckled Swellshark	Fowler et al., 1997	DD	Unknown	2015
<i>Cephaloscyllium sufflans</i>	Scyliorhinidae	Balloon Shark	Fowler et al., 1997	NT	Decreasing	2019
<i>Cephaloscyllium umbratile</i>	Scyliorhinidae	Japanese Swellshark	Fowler et al., 1997	DD	Unknown	2007
<i>Cephaloscyllium variegatum</i>	Scyliorhinidae	Saddled Swellshark	Fowler et al., 1997	NT	Decreasing	2018
<i>Cephaloscyllium ventriosum</i>	Scyliorhinidae	Swell Shark	Fowler et al., 1997	LC	Unknown	2015

<i>Cephaloscyllium zebrium</i>	Scyliorhinidae	Narrowbar Swellshark	Fowler et al., 1997	DD	Unknown	2015
<i>Cetorhinus maximus</i>	Cetorhinidae	Basking Shark	Fowler et al., 1997; Vannuccini 1999	EN	Decreasing	2018
<i>Cirrhigaleus asper</i>	Squalidae	Roughskin Shark/Roughsk in Spurdog	Fowler et al., 1997; Vannuccini 1999	VU	Unknown	2017
<i>Cirrhigaleus barbifer</i>	Squalidae	Mandarin Dogfish	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2007
<i>Dalatias licha</i>	Dalatiidae	Kitefin Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2017
<i>Dasyatis pastinaca</i>	Dasyatidae	Common Stingray	Vannuccini 1999	DD	Unknown	2003
<i>Deania calcea</i>	Centrophoridae	Birdbeak Dogfish	Fowler et al., 1997; Vannuccini 1999	LC	Unknown	2003
<i>Echinorhinus brucus</i>	Echinorhinidae	Bramble Shark	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2003
<i>Eusphyra blochii</i>	Sphyrnidae	Winghead Shark	Fowler et al., 1997	EN	Decreasing	2015
<i>Galeocerdo cuvier</i>	Carcharhinidae	Tiger Shark	Fowler et al., 1997; Vannuccini 1999	NT	Decreasing	2018
<i>Galeorhinus galeus</i>	Triakidae	Tope Shark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2020
<i>Galeus antillensis</i>	Pentanchidae	Antilles Catshark	Vannuccini 1999	DD	Unknown	2004
<i>Galeus arae</i>	Pentanchidae	Roughtail Catshark	Vannuccini 1999	LC	Unknown	2004
<i>Galeus atlanticus</i>	Pentanchidae	Atlantic Sawtail Catshark	Vannuccini 1999	NT	Unknown	2007
<i>Galeus cadenati</i>	Pentanchidae	Longfin Sawtail Catshark	Vannuccini 1999	DD	Unknown	2004

<i>Galeus eastmani</i>	Pentanchidae	Gecko Catshark	Vannuccini 1999	LC	Unknown	2007
<i>Galeus gracilis</i>	Pentanchidae	Slender Sawtail Shark	Vannuccini 1999	DD	Unknown	2015
<i>Galeus longirostris</i>	Pentanchidae	Longnose Sawtail Catshark	Vannuccini 1999	DD	Unknown	2007
<i>Galeus melastomus</i>	Pentanchidae	Blackmouth Catshark	Vannuccini 1999	LC	Stable	2003
<i>Galeus mincaronei</i>	Pentanchidae	Southern Sawtail Catshark	Vannuccini 1999	VU	Decreasing	2004
<i>Galeus murinus</i>	Pentanchidae	Mouse Catshark	Vannuccini 1999	LC	Stable	2014
<i>Galeus nipponensis</i>	Pentanchidae	Broadfin Sawtail Catshark	Vannuccini 1999	DD	Unknown	2008
<i>Galeus piperatus</i>	Pentanchidae	Peppered Catshark	Vannuccini 1999	LC	Unknown	2006
<i>Galeus polli</i>	Pentanchidae	Galeus polli	Vannuccini 1999	LC	Stable	2004
<i>Galeus priapus</i>	Pentanchidae	Phallic Catshark	Vannuccini 1999	LC	Unknown	2017
<i>Galeus sauteri</i>	Pentanchidae	Blacktip Sawtail Catshark	Vannuccini 1999	DD	Unknown	2007
<i>Galeus shcultzi</i>	Pentanchidae	Dwarf Sawtail Catshark	Vannuccini 1999	DD	Unknown	2007
<i>Galeus springeri</i>	Pentanchidae	Galeus springeri	Vannuccini 1999	DD	Unknown	2004
<i>Glaucostegus typus</i>	Glaucostegidae	Giant Guitarfish	Vannuccini 1999	CR	Decreasing	2018
<i>Hemipristis elongata</i>	Hemigaleidae	Snaggletooth Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2015
<i>Hexanchus griseus</i>	Hexanchidae	Bluntnose Sixgill Shark	Fowler et al., 1997; Vannuccini 1999	NT	Unknown	2005
<i>Isurus oxyrinchus</i>	Lamnidae	Shortfin Mako	Fowler et al., 1997; Vannuccini 1999	EN	Decreasing	2018
<i>Isurus paucus</i>	Lamnidae	Longfin Mako	Fowler et al., 1997;	EN	Decreasing	2018

			Vannuccini 1999			
<i>Lamna ditropis</i>	Lamnidae	Salmon Shark	Fowler et al., 1997; Vannuccini 1999	LC	Stable	2018
<i>Lamna nasus</i>	Lamnidae	Porbeagle Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2018
<i>Mestelus manazo</i>	Triakidae	Starspotted Smoothhound	Fowler et al., 1997	DD	Unknown	2007
<i>Mustelus californicus</i>	Triakidae	Gray Smooth Hound	Vannuccini 1999	LC	Unknown	2014
<i>Mustelus griseus</i>	Triakidae	Spotless Smooth Hound	Vannuccini 1999	DD	Unknown	2007
<i>Nebrius ferrugineus</i>	Ginglymostom atidae	Tawny Nurse Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2003
<i>Negaprion acutidens</i>	Carcharhinidae	Sharptooth Lemon Shark/ Sicklefin Lemon Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2003
<i>Odontaspis ferox</i>	Odontaspididae	Smalltooth Sand Tiger Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2015
<i>Odontaspis noronhai</i>	Odontaspididae	Bigeye Sand Tiger Shark	Fowler et al., 1997	LC	Unknown	2018
<i>Poroderma africanum</i>	Scyliorhinidae	Pyjama Shark	Fowler et al., 1997	LC	Increasing	2019
<i>Poroderma pantherinum</i>	Scyliorhinidae	Leopard Catshark	Fowler et al., 1997	LC	Increasing	2019
<i>Prionace glauca</i>	Carcharhinidae	Blue Shark	Vannuccini 1999	NT	Decreasing	2018
<i>Pristiophorus nudipinnis</i>	Pristiophoridae	Southern Sawshark	Vannuccini 1999	LC	Stable	2015
<i>Pristis clavata</i>	Pristidae	Dwarf Sawfish	Fowler et al., 1997	EN	Decreasing	2012
<i>Pristis pectinata</i>	Pristidae	Smalltooth Sawfish/Wide Sawfish	Fowler et al., 1997	CR	Decreasing	2012

<i>Pristis pristis</i>	Pristidae	Large-tooth Sawfish	Fowler et al., 1997	CR	Decreasing	2013
<i>Pristis zijsron</i>	Pristidae	Longcomb Sawfish/Green Sawfish	Fowler et al., 1997	CR	Decreasing	2012
<i>Rhincodon typus</i>	Rhincodontidae	Whale Shark	Vannuccini 1999	EN	Decreasing	2016
<i>Schroederichthys bivius</i>	Scyliorhinidae	Narrowmouth Catshark	Fowler et al., 1997	DD	Unknown	2005
<i>Schroederichthys chilensis</i>	Scyliorhinidae	Chilean Catshark	Fowler et al., 1997	DD	Unknown	2004
<i>Schroederichthys maculatus</i>	Scyliorhinidae	Narrowtail Catshark	Fowler et al., 1997	LC	Unknown	2004
<i>Schroederichthys saurissqualus</i>	Scyliorhinidae	Lizard Catshark	Fowler et al., 1997	VU	Unknown	2004
<i>Schroederichthys tenuis</i>	Scyliorhinidae	Slender Catshark	Fowler et al., 1997	DD	Unknown	2004
<i>Scyliorhinus besnardi</i>	Scyliorhinidae	Scyliorhinus besnardi	Fowler et al., 1997	DD	Unknown	2004
<i>Scyliorhinus boa</i>	Scyliorhinidae	Boa Catshark	Fowler et al., 1997	LC	Unknown	2004
<i>Scyliorhinus canicula</i>	Scyliorhinidae	Small Spotted Cat Shark	Fowler et al., 1997	LC	Stable	2008
<i>Scyliorhinus capensis</i>	Scyliorhinidae	Yellow Spotted Catshark	Fowler et al., 1997	NT	Decreasing	2019
<i>Scyliorhinus cervigoni</i>	Scyliorhinidae	Scyliorhinus cervigoni	Fowler et al., 1997	DD	Unknown	2006
<i>Scyliorhinus comoroensis</i>	Scyliorhinidae	Comoro Catshark	Fowler et al., 1997	DD	Unknown	2018
<i>Scyliorhinus garmani</i>	Scyliorhinidae	Brownspotted Catshark	Fowler et al., 1997	DD	Unknown	2007
<i>Scyliorhinus haecklii</i>	Scyliorhinidae	Scyliorhinus haecklii	Fowler et al., 1997	DD	Unknown	2004
<i>Scyliorhinus hesperius</i>	Scyliorhinidae	Scyliorhinus hesperius	Fowler et al., 1997	DD	Unknown	2004
<i>Scyliorhinus meadi</i>	Scyliorhinidae	Scyliorhinus meadi	Fowler et al., 1997	DD	Unknown	2006
<i>Scyliorhinus retifer</i>	Scyliorhinidae	Scyliorhinus retifer	Fowler et al., 1997	LC	Increasing	2006
<i>Scyliorhinus stellaris</i>	Scyliorhinidae	Nursehound	Fowler et al., 1997	NT	Unknown	2006

<i>Scyliorhinus tokubee</i>	Scyliorhinidae	Izu Catshark	Fowler et al., 1997	DD	Unknown	2008
<i>Scyliorhinus torazame</i>	Scyliorhinidae	Cloudy Catshark	Fowler et al., 1997	LC	Unknown	2008
<i>Scyliorhinus torrei</i>	Scyliorhinidae	Dwarf Catshark	Fowler et al., 1997	LC	Unknown	2004
<i>Scymnodon plunketi</i>	Somniosidae	Plunket's Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2017
<i>Somniosus microcephalus</i>	Somniosidae	Greenland Shark	Vannuccini 1999	NT	Unknown	2006
<i>Sphyrna corona</i>	Sphyrnidae	Scalloped Bonnethead	Vannuccini 1999	NT	Unknown	2004
<i>Sphyrna lewini</i>	Sphyrnidae	Scalloped Hammerhead	Vannuccini 1999	CR	Decreasing	2018
<i>Sphyrna media</i>	Sphyrnidae	Scoophead Shark	Vannuccini 1999	DD	Unknown	2006
<i>Sphyrna mokarran</i>	Sphyrnidae	Great Hammerhead	Vannuccini 1999	CR	Decreasing	2018
<i>Sphyrna tiburo</i>	Sphyrnidae	Bonnethead Shark	Vannuccini 1999	LC	Stable	2014
<i>Sphyrna tudes</i>	Sphyrnidae	Smalleye Hammerhead	Vannuccini 1999	VU	Decreasing	2006
<i>Sphyrna zygaena</i>	Sphyrnidae	Smooth Hammerhead	Fowler et al., 1997	VU	Decreasing	2018
<i>Squalus acanthias</i>	Squalidae	Piked Dogfish/Spiny Dogfish	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2016
<i>Squalus cubensis</i>	Squalidae	Cuban Dogfish	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2006
<i>Squalus mitsukurii</i>	Squalidae	Shortspine spurdog	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2007
<i>Squatina aculeata</i>	Squatinidae	Sawback Angelshark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2017
<i>Squatina oculata</i>	Squatinidae	Smoothback Angelshark	Fowler et al., 1997	CR	Decreasing	2017

<i>Squatina squatina</i>	Squatinidae	Angelshark	Fowler et al., 1997	CR	Decreasing	2017
<i>Triaenodon obesus</i>	Carcharhinidae	Whitetip Reef Shark	Vannuccini 1999	NT	Unknown	2005

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